

SEA TURTLES OF THE SOUTHEASTERN UNITED STATES, WITH EMPHASIS
ON THE LIFE HISTORY AND POPULATION DYNAMICS OF
THE LOGGERHEAD TURTLE, CARETTA CARETTA

Tyrrell Arthur Henwood

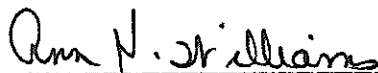
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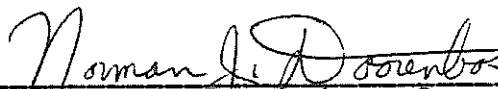
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A Dissertation
Submitted to
the Graduate Faculty of
Auburn University
in Partial Fulfillment of the
Requirements for the
Degree of
Doctor of Philosophy

Auburn, Alabama

March 20, 1987

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VITA

Tyrrell Arthur Henwood was born in Baltimore, Maryland, on September 3, 1948, the son of Reginald Joseph and Christine (Arthur) Henwood. He attended public school in Cleveland, Ohio, and moved to Gadsden, Alabama, in 1955. He graduated from Gadsden High School in 1966. After two years of study at the University of Alabama, he entered the U.S. Navy where he served from 1968-1972. Following military service, he returned to the University of Alabama and received the degree of Bachelor of Science (Biology) in May, 1975. He then attended the University of South Alabama and received the Master of Science degree (Biology - marine emphasis) in May, 1978. He worked as an environmental consultant for two years before assuming his present position as a fisheries biologist with the National Marine Fisheries Service. He was married to Jean, daughter of John and Frances (Murphy) Young, in July, 1980. They have two sons, Andrew Joseph and Brian Scott.

DISSERTATION ABSTRACT
SEA TURTLES OF THE SOUTHEASTERN UNITED STATES, WITH EMPHASIS
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Doctor of Philosophy, March, 1987
(M.S., University of South Alabama, 1978)
(B.S., University of Alabama, 1975)

181 Typed Pages

Directed by Stephen P. Malvestuto

Populations of five species of sea turtles occurring in the southern North Atlantic and Gulf of Mexico were sampled with trawling gear from 1978 through 1984. The loggerhead turtle, Caretta caretta, was the most abundant species encountered during these investigations and constituted 4,505 capture records. Green turtles, Chelonia mydas, and Kemp's ridley turtles, Lepidochely kempii, were captured infrequently (19 and 50 capture records, respectively), while leatherback, Dermochelys coriacea, and hawksbill, Eretmochelys imbricata, turtles were rarely encountered (4 and 2 capture records, respectively).

For the loggerhead turtle, data were sufficient for investigations of morphometric relationships, movements,

seasonal changes in relative abundance, flipper tag retention, populations in the Cape Canaveral ship channel, age, growth, survival and mortality. Kemp's ridley and green turtle captures provided limited information on seasonal distributions and movements of these species.

TABLE OF CONTENTS

LIST OF TABLES	viii
LIST OF FIGURES	x
I. GENERAL INTRODUCTION	1
II. REVIEW OF LITERATURE	3
III. DATA COLLECTION	9
IV. SOME MORPHOMETRIC RELATIONSHIPS IN THE WESTERN ATLANTIC LOGGERHEAD TURTLE, <u>CARETTA CARETTA</u> . . .	15
V. AGE, GROWTH, SURVIVAL AND MORTALITY IN LOGGERHEAD TURTLES, <u>CARETTA CARETTA</u> , ESTIMATED FROM TAG-RECAPTURE EXPERIMENTS	40
VI. MOVEMENTS AND SEASONAL CHANGES IN LOGGERHEAD TURTLE, <u>CARETTA CARETTA</u> , AGGREGATIONS IN THE VICINITY OF CAPE CANAVERAL, FLORIDA (1978-1983) .	72
VII. SEASONALITY AND ABUNDANCE OF LOGGERHEAD SEA TURTLES (<u>CARETTA CARETTA</u>) IN FIVE EASTERN FLORIDA CHANNELS AND INLETS	96
VIII. LOSSES OF MONEL FLIPPER TAGS FROM LOGGERHEAD SEA TURTLES, <u>CARETTA CARETTA</u>	119
IX. KEMP'S RIDLEY (<u>LEPIDOCHELYS KEMPII</u>) AND GREEN (<u>CHELONIA MYDAS</u>) TURTLES CAPTURED BY TRAWL IN THE VICINITY OF CAPE CANAVERAL, FLORIDA (1979-1984)	135
X. SUMMARY	153
BIBLIOGRAPHY	161

LIST OF TABLES

IV.	1.	Conversion formulae for comparisons between different measurement techniques in loggerhead turtles, <u>Caretta caretta</u>	30
	2.	Comparisons of mean size of nesting female loggerhead turtles, <u>Caretta caretta</u> , of the western Atlantic as reported in the literature.	31
	3.	Coefficient of condition (C) in subadult and adult loggerhead turtles, <u>Caretta caretta</u>	33
V.	1.	Asymptotic estimates of parameters a and k with standard errors for non-linear regression of logistic and von Bertalanffy equations and GM linear regression of the von Bertalanffy equation	51
VI.	1.	Summary of monthly occurrence of loggerhead turtles, <u>Caretta caretta</u> , in the Cape Canaveral area by three sex categories (adult male, adult female and subadult).	82
	2.	Summary of subadult loggerhead turtle, <u>Caretta caretta</u> , captures, recaptures and CPUE in the Cape Canaveral ship channel (July to November, 1980)	88
VII.	1.	Estimated probability of turtle capture in a Cape Canaveral ship channel substation using an 18-m fish trawl.	107
	2.	Estimated number of turtles (N) at Cape Canaveral ship channel by station and survey period (1981-1982).	108
	3.	Estimated loggerhead turtle abundance during quarterly surveys of St. Mary's entrance - King's Bay, Ponce de Leon Inlet, Ft. Pierce Inlet and St. Lucie Inlet	110

	4.	Summary of catch per unit effort (CPUE) of loggerhead turtles, <u>Caretta caretta</u> , in the Cape Canaveral ship channel (1978-1983) . . .	108
VIII.	1.	Summary of loggerhead turtle recaptures by days-at-large increments . . . . .	.123
	2.	Probabilities of tag loss in loggerhead turtles, <u>Caretta caretta</u> , calculated by 100-day increments . . . . .	.124
	3.	Probabilities of tag loss in loggerhead turtles, <u>Caretta caretta</u> , calculated by 5-day increments over the first 100 days-at-large . . . . .	.129
	4.	Percent tag loss in loggerhead turtles, <u>Caretta caretta</u> , over the first 90 days-at-large . . . . .	.132
IX.	1.	Summary of green turtle, <u>Chelonia mydas</u> , captures in the Canaveral area and adjacent shrimping grounds . . . . .	.139
	2.	Summary of Kemp's ridley, <u>Lepidochelys kempii</u> , captures in the Canaveral area and adjacent shrimping grounds . . . . .	.143
	3.	Summary of Kemp's ridley, <u>Lepidochelys kempii</u> captures from Georgia and South Carolina . . . . .	.145

LIST OF FIGURES

IV.	1.	Sea turtle carapace measurements and tail measurements used in analyses	19
	2.	Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (<u>Caretta caretta</u>)	23
	3.	Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (<u>Caretta caretta</u>)	25
	4.	Regressions of straight-line (SL) and over-curve (OC) length and width on weight. Log-log transformed formulae are presented.	26
	5.	Positions of male, female and subadult loggerhead turtles, <u>Caretta caretta</u> , in discriminant space defined by two discriminant functions	28
V.	1.	Computed yearly growth (cm/yr) on days-at-large in loggerhead turtles, <u>Caretta caretta</u>	48
	2.	Age/size estimates for loggerhead turtles, <u>Caretta caretta</u> , fitting the von Bertalanffy and logistic models to tag-recapture data using a known hatchling size of 4.5 cm	52
	3.	Age/size estimates for loggerhead turtles, <u>Caretta caretta</u> , fitting the von Bertalanffy model to tag-recapture data using an assumed age of five years at 50 cm	54
	4.	Catch curve of natural logarithm of frequency on age in loggerhead turtles, <u>Caretta caretta</u> , using running averages of three years.	55

	5.	Catch curve of natural logarithm of frequency on age in loggerhead turtles, <u>Caretta caretta</u> .	65
VI.	1.	Description of the primary study area including local nesting beaches at Canaveral National Seashore, Kennedy Space Center and Melbourne Beach . . . . .	.77
	2.	Length frequency distribution of loggerhead turtles, <u>Caretta caretta</u> , captured in the Cape Canaveral area . . . . .	.79
	3.	Length frequencies of loggerhead turtles, <u>Caretta caretta</u> , captured in the Cape Canaveral area plotted by cumulative percent.	.80
	4.	Percent composition of loggerhead turtles <u>Caretta caretta</u> , in three sex categories (adult male, adult female and subadult) captured in the Cape Canaveral area by month.	.83
	5.	Summary of long-distance recaptures from loggerhead turtles, <u>Caretta caretta</u> , originally captured and tagged in the Cape Canaveral area . . . . .	.87
VII.	1.	Description of five eastern Florida navigational channels and inlets surveyed in this study . . . . .	.100
	2.	Description of the Cape Canaveral Ship Channel survey area . . . . .	.103
	3.	Loggerhead turtle abundance estimates (N) from quarterly surveys of the Cape Canaveral ship channel . . . . .	.112
VIII.	1.	Regression of probability of tag loss on days-at-large for loggerhead turtles, <u>Caretta caretta</u> . Two types of flipper tags are compared . . . . .	.126
	2.	Regression of probability of tag loss on days-at-large for loggerhead turtles, <u>Caretta caretta</u> . . . . .	.130
IX.	1.	Description of the primary study area including local nesting beaches at Canaveral National Seashore, Kennedy Space Center and Melbourne Beach . . . . .	.137

2. Summary of green turtle, Chelonia mydas, captures in the vicinity of Cape Canaveral, Florida140
3. Summary of Kemp's ridley, Lepidochelys kempii, captures in the vicinity of Cape Canaveral, Florida142
4. Summary of Kemp's ridley, Lepidochelys kempii, captures off Georgia and South Carolina146
5. Movements of Kemp's ridley turtles, Lepidochelys kempii, based on tag returns. . .147

I. GENERAL INTRODUCTION

Sea turtle populations throughout the world have declined significantly in recent years. Of the species encountered in the United States Fisheries Conservation Zone (FCZ), all have been listed under the Endangered Species Act (1973) as either endangered or threatened. The Kemp's ridley turtle, Lepidochelys kempii (Garman 1880), the hawksbill turtle, Eretmochelys imbricata (Linnaeus 1766), and the leatherback turtle, Dermochelys coriacea (Linnaeus 1766) are listed as endangered species. The loggerhead sea turtle, Caretta caretta (Linnaeus 1758), the green turtle, Chelonia mydas (Linnaeus 1758) and the Olive ridley turtle, Lepidochelys olivacea (Eschscholtz 1829) are identified as threatened, except Florida breeding populations of green turtles which are listed as endangered¹.

With increased emphasis on protection and preservation of sea turtles, the development of a sound management plan

¹Common and scientific names follow recommendations of the International Union for Conservation of Nature and Natural Resources (IUCN) Amphibia-Reptilia Red Data Book (1982).

has become imperative. In order to produce an effective conservation plan, certain aspects of turtle life histories must be understood. At the present time, gaps in our knowledge of the life histories of all species exist, making it difficult to identify critical habitats or life stages.

For a number of years, nesting beaches throughout the world have been monitored; female turtles have been studied and biological aspects of incubation, hatching success, clutch size and predation have been closely examined. This short phase of turtle life history has been researched more extensively than any other, due primarily to the vulnerability of turtles to capture and observation. The remainder of the sea turtle life history is poorly understood because subadults, males and non-nesting females do not come ashore, and must be captured and studied at sea.

Present are results of several independent research investigations conducted by the National Marine Fisheries Service (NMFS) from 1978 through 1984. The goals of these studies were to investigate sea turtle populations in United States waters. Over the course of these investigations, three species of turtles (greens, Kemp's ridleys and loggerheads) were captured in sufficient numbers for analysis. Of these species, the loggerhead turtle was by far the most abundant and has, therefore, received the most attention.

II. REVIEW OF LITERATURE

Nesting populations of sea turtles have been studied extensively throughout the world, and a large volume of literature concerning this phase of their life histories is available. Unfortunately, little is known about the life histories of subadults, adult males and non-nesting females. A brief summary of the existing knowledge and literature pertaining to the species encountered in these investigations follows.

The Green Turtle (*Chelonia mydas*)

Green turtles are circumglobally distributed mainly in waters between the northern and southern 20° C isotherms (Hirth, 1971). In the western Atlantic, several major nesting assemblages have been identified and studied (Peters, 1954; Carr and Ogren, 1960; Duellman, 1961; Parsons, 1962; Pritchard, 1969a; Schulz 1975; Carr et al., 1978). In the continental U.S., however, the only known green turtle nesting occurs on the Atlantic coast of Florida (Ehrhart, 1979).

While nesting activity is a factor in determining population distributions, the remaining portion of the green turtle's life is spent on the foraging grounds. Some of the principal feeding pastures in the western Atlantic Ocean include: upper west coast of Florida, northwestern coast of Yucatan peninsula, south coast of Cuba, Mosquito Coast of Nicaragua, Caribbean coast of Panama, scattered areas along Colombia, and scattered areas off the Brazilian coast (Hirth, 1971). The preferred food sources in these areas are: Cymodocea, Thalassia, Zostera, Sagittaria and Vallisneria (Babcock, 1937; Underwood, 1951; Carr, 1954; Carr, 1952 ; Neill, 1958; Mexico, 1966).

Although no green turtle feeding pastures or major nesting beaches have been identified on the southeast Atlantic coast, evidence provided by Mendonca and Ehrhart (1982) indicates that immature green turtles may utilize lagoonal systems during periods of their lives. These authors identified a population of young green turtles (carapace length 29.5 - 75.4 cm) believed to be resident in the Mosquito Lagoon, Florida. The Indian River system, of which Mosquito Lagoon is a part, supported a green turtle fishery during the late 1800's (Ehrhart, 1983), and these turtles may be remnants of this historical colony.

The Kemp's Ridley Turtle (*Lepidochelys kempii*)

Of the seven extant species of sea turtles of the world, the Kemp's ridley is probably in the greatest danger of extinction. The only major nesting area for this species is a single stretch of beach near Rancho Nuevo, Tamaulipas, Mexico (Carr, 1963; Hildebrand, 1963). Virtually the entire world population of adult females nest annually in this single locality (Pritchard, 1969b).

When nesting aggregations at Rancho Nuevo were discovered in 1947, adult female populations were estimated to be in excess of 40,000 individuals (Hildebrand, 1963). By the early 1970's, the world population estimate of mature female Kemp's ridleys had been reduced to from 2500-5000 individuals. Most recent estimates of the total population of sexually mature female Kemp's ridleys are less than 600-700 turtles (Bacon et al., 1984).

The foraging range of mature Kemp's ridley turtles is believed to be restricted to the Gulf of Mexico. Evidence provided by tagging programs (Chavez, 1968) suggests that post-nesting females move in comparable numbers to the north (mostly to Louisiana) and to the south (mostly to Campeche) (Pritchard and Marquez, 1973). It is assumed that adult male turtles follow similar migratory patterns.

Movements of hatchling Kemp's ridley turtles may be determined by current patterns: either the loop current for

northward transport or an eddy for southward transport, with occasional transportation through the Florida Straits via the Gulf Stream (Hildebrand, 1982). Young Kemp's ridley turtles are known to occur in eastern U.S. coastal waters from Florida to Canadian portions of the Gulf of Maine (Lazell, 1980). Pritchard and Marquez (1973) suggest that passive transportation via the Gulf Stream up the eastern coast of the U.S. may be the usual dispersal pattern of young Kemp's ridley turtles. They speculate that turtles feed and grow rapidly during passive transport, and by the time they reach offshore waters of New England they are large enough for active swimming. At this stage they reverse the direction of travel toward the Gulf of Mexico.

Kemp's ridley turtles feed primarily in shallow coastal waters on bottom-living crustaceans (Hildebrand, 1982). Organisms identified from stomachs include crabs (Palyonchus, Hepatus, Callinectes, Panopeus, Menippe, Ovalipes, Calappa, Portunus, Arenaeus), fish (Lutjanus, Leiostomus) and molluscs (Noculana, Corbula, Mulinia, Nassarius) (Dobie et al., 1961; Pritchard and Marquez, 1973). All of these genera are forms which commonly occur in the Gulf of Mexico and the eastern coast of the United States.

The Loggerhead Turtle (*Caretta caretta*)

In the western Atlantic Ocean, loggerhead sea turtles occur from Argentina northward to Nova Scotia including the Gulf of Mexico and the Caribbean Sea (Carr, 1952). Sporadic nesting is reported throughout the tropical and warmer temperate range of distribution, but the most important nesting areas are the Atlantic coast of Florida, Georgia and South Carolina (Carr and Carr, 1978). The Florida nesting population of Caretta has been estimated to be the second largest in the world (Ross, 1982).

The foraging range of the loggerhead sea turtle extends throughout the warm waters of the U.S. continental shelf (Rebel, 1974). On a seasonal basis, loggerhead turtles are common as far north as the Canadian portions of the Gulf of Maine (Lazell, 1980), but during cooler months of the year, distributions shift to the south (Shoop et al., 1981). Loggerheads frequently forage around coral reefs, rocky places and old boat wrecks; they commonly enter bays, lagoons and estuaries (Ernst and Barbour, 1972). Aerial surveys of loggerhead turtles at sea indicate that they are most common in waters less than 50-m in depth (Shoop et al., 1981; Fritts et al., 1983), but they occur pelagically as well. Shoop et al. (1981) speculated that loggerhead turtles sighted in deep oceanic water were probably in transit to other areas.

The primary food sources of the loggerhead turtle are benthic invertebrates including molluscs, crustaceans and sponges (Mortimer, 1982). Crabs and conchs were identified (Carr, 1952) as the most frequently found items in stomachs, although loggerheads often eat fish, clams, oysters, sponges and jellyfish. Ernst and Barbour (1972) included marine grasses and seaweeds, mussels, borers, squid, shrimp, amphipods, crabs, barnacles and sea urchins among the foods of loggerhead turtles². The horseshoe crab (Limulus polyphemus) has been identified as a major food source of loggerheads in Mosquito Lagoon, Florida (Mortimer, 1982).

Nesting aggregations of loggerhead sea turtles along the U.S. Atlantic coast have received considerable attention in recent years, but most studies have been limited to nesting migrations of adult females, development of eggs and behavior of hatchlings (Ernst and Barbour, 1972). Little information on the life history of subadults and adult males is available. The work of Mendonca and Ehrhart (1982) suggests that subadult loggerhead turtles may use lagoonal systems as preferred habitats during stages of their life cycles.

²Common names for food items are used when no generic names were provided.

III. DATA COLLECTION

Since 1977, the National Marine Fisheries Service (NMFS), Southeast Fisheries Center, Mississippi Laboratories, have conducted sea turtle field research in the Gulf of Mexico and southern North Atlantic. Five independent research projects have been completed. All projects employed trawling equipment as the sampling device used in the capture of sea turtles. Type and size of trawl varied according to season, area and project objectives. A description of sampling methodology and goals of each project follows.

Sea Turtle Habitat Surveys

The project goal was to institute and pursue comprehensive surveys of sea turtles and their habitats off the southeastern United States. The major emphasis of this project was directed toward systematic sampling of the Port Canaveral, Florida ship channel. Initial surveys conducted in February and March of 1978 were exploratory in nature, while subsequent surveys incorporated a systematic sampling design.

Initial cruises addressed factors which may have contributed to the high concentrations of sea turtles observed in the Canaveral ship channel (Carr et al., 1980), while later surveys were designed to provide population density and relative abundance estimates. In all cruises, captured turtles were identified, carapace dimensions measured, and tags were applied. In many cases the turtles were weighed, and some data were collected on tail length and cloacal body temperatures. A station sheet containing environmental data and sea turtle biological data was completed for each tow. Additional information on other organisms captured in the trawl (by-catch) were collected in some instances.

The trawl most commonly employed during the surveys was a 18.5-m flat shrimp trawl. Other trawls ranged in size from a 12.3-m flat shrimp trawl to a 23.0-m flat trawl. A 18.6-m Mongoose trawl was also used to determine whether height of the net opening altered the rate of turtle captures.

Incidental Catch and Mortality Project

This project was instituted to provide information on the incidental capture and associated mortality of sea turtles off the southeastern United States. Trained observers were placed aboard commercial shrimp vessels

operating on the major shrimp grounds in the Gulf of Mexico and southern North Atlantic. Data were collected from 1979 through 1981.

The sampling routine employed by NMFS observers was: after the trawl catch was dumped on deck, captured turtles were identified, measured and tagged. A station sheet was completed for each tow, with turtle species and size, tag numbers, total live catch, total shrimp catch and other pertinent information recorded. By-catch station sheets and length frequency sheets were completed from samples taken on the first tow of each fishing day. Additional by-catch station sheets were completed when the trawler moved to different grounds or if a change in species composition of the by-catch was observed.

Trawls employed by the shrimp vessels varied according to size of the engine, size of the vessel, bottom type and target species. Trawls were continuously modified by commercial fishermen to increase catch rates of the target species. Trawls employed ranged from two 12.3-m flat trawls to four 12.3-m semi-balloon trawls.

Sea Turtle Excluder Trawl Project

The goal of this project was to design an apparatus for use with existing shrimping gear which would effectively prevent the incidental capture of sea turtles. Initial design and testing of prototype models was conducted during

1977, and field trials continued through 1982. Trained observers aboard cooperative and chartered shrimp trawlers began data collection in 1978.

The sampling routine employed by NMFS observers was similar to that of the Incidental Catch and Mortality Project. The major difference was that instead of taking a single by-catch sample from the total catch, at least two independent samples were taken. In some cases up to four samples were taken per tow. This procedure allowed comparison of catch and catch rates between the standard shrimp trawl and the modified trawl with an excluder device. Any turtles captured were measured, tagged and released. A standard station sheet containing environmental, turtle and catch information was completed for each net. By-catch samples from each net were also recorded.

A wide variety of trawl types and modifications were tested during this project. Trawl sizes ranged from 12.9-m flat trawls to 24.6-m Mongoose trawls.

Cape Canaveral Sea Turtle Rescue Mission

This project was instituted to capture and remove sea turtles from the Port Canaveral, FL ship channel. It was initiated when U. S. Army Corps of Engineers (COE) channel dredging operations were linked to sea turtle mortalities in the area. A local shrimp trawler was chartered to clear sea turtles from areas in the dredge path. A NMFS and COE

observer aboard the trawler recorded data associated with the effort.

All captured turtles were identified, measured, weighed, tagged and relocated to offshore release sites. A station sheet containing pertinent information was completed for each tow. No by-catch or length frequency data were collected.

A two seam 24.6-m shrimp trawl was used throughout the project.

East Coast Channel Surveys

The objective of this project was to derive seasonal estimates of sea turtle abundance in five eastern Florida navigation channels. These surveys provided a continuation of Cape Canaveral Habitat Survey efforts and established estimates of population size in four additional channel areas.

Sampling methodology used in the channel surveys was based on Habitat Surveys design. Each channel was separated into 1,483-m stations which were divided into 30-m wide substations. Initial substation and direction of tow were randomly selected prior to each survey. Subsequent stations were sampled alternately in the direction of the beginning tow until either end of the channel was reached. Station sequence was then reversed and random sampling of substations was continued until all had been sampled.

Records of sea turtle captures from all projects were merged to form a single sea turtle data base. Recaptures of turtles bearing NMFS tags were included in the file bringing the number of sea turtle records to 4,579. Four thousand five hundred and five of the total were loggerhead (Caretta caretta), fifty were Kemp's ridley (Lepidochelys kempii), nineteen were green (Chelonia mydas), three were leatherback (Dermochelys coriacea) and two were hawksbill (Eretmochelys imbricata).

In some analyses, turtles captured in or near the Canaveral ship channel were treated independently. Captures in the Canaveral area consisted of 3,729 loggerhead turtles, 9 green turtles and 15 Kemp's ridleys. An additional 25 Kemp's ridleys and 10 greens were captured by a single shrimp trawler operating out of Cape Canaveral, and were included in ridley and green turtle analyses.

IV. SOME MORPHOMETRIC RELATIONSHIPS IN THE WESTERN
ATLANTIC LOGGERHEAD TURTLE, CARETTA CARETTA

By

Tyrrell A. Henwood and Jonathan D. Moulding

ABSTRACT

Morphometric relationships are described for western Atlantic loggerhead turtles, Caretta caretta, over a size range of 44-114 cm total carapace length (14-172 kg in weight). Regressions of length and width (measured over-the-curve and straight-line) showed good linear fits in all combinations. Regressions of length and width on weight were best fitted to a power function. Condition factor (C), based on the length-weight relationship for adult and subadult turtles, varied seasonally, with lowest factors during winter months and highest during warmer periods of faster growth.

Relative growth of loggerhead turtle carapace dimensions changed as animals matured and resulted in an

ontogenetic change in the shape of the animals. Growth in adult turtles was restricted primarily to the longitudinal axis.

Formulae for conversion of four possible length measurements were developed for both over-the-curve and straight-line techniques. These formulae provided a means to compare previously published size information, despite differences in measurement techniques.

The relationship of total tail length to total straight-line carapace length was found to be an accurate indicator of sex in mature male turtles, and is assumed to be a good indicator of sex in adult female turtles as well. In subadult turtles, the tail measurement does not appear to be a usable indicator of sex.

INTRODUCTION

Sea turtle researchers commonly measure carapace dimensions as a routine part of their tagging projects (Gallagher et al., 1972; Kaufmann, 1975; Worth and Smith, 1976; Davis and Whiting, 1977; Fletemeyer, 1982; Bjorndal et al., 1983). Several researchers have also weighed turtles as part of their standard measurement procedures (Hughes, 1974; Ehrhart and Yoder, 1978; Ehrhart, 1979). These data have been used to describe length, width and weight relationships in nesting females, and to document

size compositions within discrete nesting populations. While these studies contain valuable information on specific assemblages of adult females, they are not always directly comparable because different measurements were taken. Nesting studies have been limited in their applicability to sea turtle populations as a whole, because only adult females were measured.

Here we describe eleven morphometric relationships in western Atlantic loggerhead turtles captured with trawling gear. This method of sampling provided a means of capturing adult males and females, and subadult turtles over a broad range of lengths and weights. Our results are of particular value because, for the first time, subadults and adult male turtles are included in the catch with adult female turtles; morphometric relationships in the population as a whole could be described. Total tail length measurements were included in our analyses to document whether such are sexually dimorphic features.

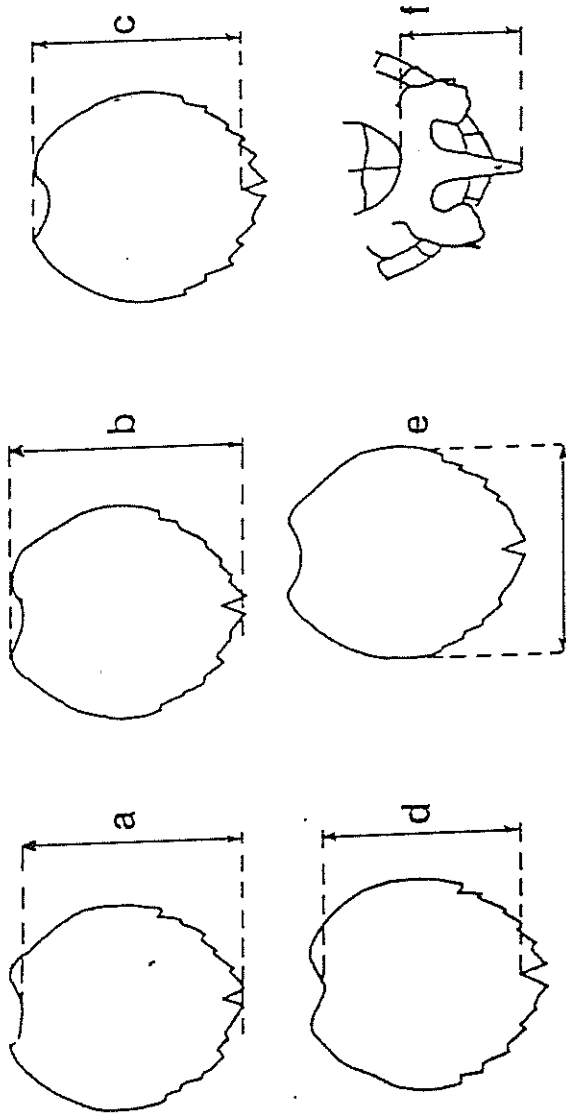
A final analysis of the length-weight relationship was performed, and coefficient of condition (C) values were calculated. These values provide a convenient means of assessing the general well-being of individual turtles within populations.

MATERIALS AND METHODS

Data Collection

Since 1978 the National Marine Fisheries Service (NMFS) has conducted sea turtle tagging and research activities in U.S. coastal waters from North Carolina to Texas. The U.S. Army Corps of Engineers (COE) has cooperated in sea turtle capture and relocation efforts in the Port Canaveral shipping channel, Florida (Moulding, 1981) and in surveys of several navigation channels on the east coast of Florida. All captured loggerheads (4505 animals) were incorporated into a single data base for our analyses.

Although sampling strategies varied according to individual project objectives, all employed trawling gear in the capture of sea turtles and all captured turtles were treated in the same manner. Straight-line (SL) measurements of carapace width (distance across the widest part of the shell perpendicular to the longitudinal body axis) and total carapace length (distance from the anteriormost edge of the 1st and 2nd marginals to the posteriormost edge of the 11th and 12th marginals) to the nearest 0.1 inch were taken with calipers (Fig. 1). When feasible, turtles were weighed with beam scales to the nearest pound. All turtles were visually sexed (based on a subjective evaluation of the tail length to carapace length relationship), tags were applied and the turtles released.



- a. Standard carapace length - precentral scute to posterior margin of postcentrals
- b. Total carapace length - shoulder to posterior margin of postcentrals
- c. Notched carapace length - shoulder to notch between postcentrals
- d. Minimum carapace length - precentral scute to notch
- e. Carapace width - widest part of shell perpendicular to longitudinal body axis
- f. Total tail length - posterior margin of plastron to tip of tail

Figure 1. Sea turtle carapace measurements and tail measurements used in analyses. Measurements conform to recommendations of Pritchard et al. (1983).

Additional carapace measurements were taken on each of 736 turtles to provide a means of comparing our results with studies in which different measurements were taken. These included standard carapace length, notched carapace length and minimum carapace length measured both over-the-curve (OC) with flexible tape and straight-line (SL) with calipers. OC measurements were performed from the same points as SL measurements with the tape stretched as tightly as possible over the curvature of the shell as described in Pritchard et al. (1983). Tail length to the nearest 0.1 inch was measured with flexible tapes in 387 instances. The tail was measured from the posterior margin of the plastron to the tip of the tail, with the tail held in as normal an extension as possible.

All measurements were converted to metric units for calculations and presentations. Length measurements used in regressions were SL total carapace length unless otherwise noted.

Data Analysis

Linear regression analyses were employed in all pairings of weights, SL and OC lengths, SL and OC widths and total tail lengths. Bartlett's three group method for Model II regression (Sokal and Rohlf, 1969) was used, because both x and y measurements were subject to error.

The condition factor (C) based on the length-weight relationship from our regressions was calculated using the formula:

$$C = W_o/W$$

W_o = observed weight

W = predicted weight.

Mean condition factors were computed by month for subadult and adult turtles.

All records in which tail length was measured in conjunction with carapace length (387 turtles) were analyzed with Biomedical Computer Programs (BMDP) stepwise discriminant analysis procedures (BMDP, 1979). The variables used in the analysis were total tail length, total carapace length and the product of these two variables.

In regressions where adult and subadult turtles were separated, 83 cm total (SL) carapace length was selected as the size where visual sexing of adults was possible. This was based primarily on verification of adult male sex identifications through analysis of serum testosterone levels (Owens, 1983), and the assumption that all males have developed secondary sexual dimorphic characteristics at this size. However, it may not reflect the size at sexual maturity, since females smaller than 83 cm have been observed nesting.

RESULTS

Regression analyses of the variables SL carapace width on SL carapace length, OC carapace width on OC carapace length and OC carapace length on SL carapace length were performed (Fig. 2). Each regression had coefficient of determination (r^2) values greater than .90 indicating that the majority of the variation could be explained by a linear regression model.

A comparison of our equation for OC length on SL length ($OC = 1.07SL + 0.36$; 95% c.i. of $B = 1.07 \pm 0.008$) with that of Frazer and Ehrhart (1983) based on the same analytical procedure ($OC = 1.02SL + 5.24$; 95% c.i. of $B = 1.02 \pm 0.034$) indicated that the slopes were different at the 95% significance level. As differences in the two equations may have been related to turtle size composition within the sample, the same analysis was done using only adult turtles. The slope of the resultant equation ($OC = 1.02SL + 4.85$; 95% c.i. of $B = 1.02 \pm 0.036$) was the same as that of Frazer and Ehrhart, (1983). Their data base was composed mainly of measurements from adult females.

The fact that the regression equation for a sample composed of adult turtles had a different slope than that for subadults, suggested that carapace relationships may change as turtles mature. To test for differences in carapace relationships, we subdivided the data into groups

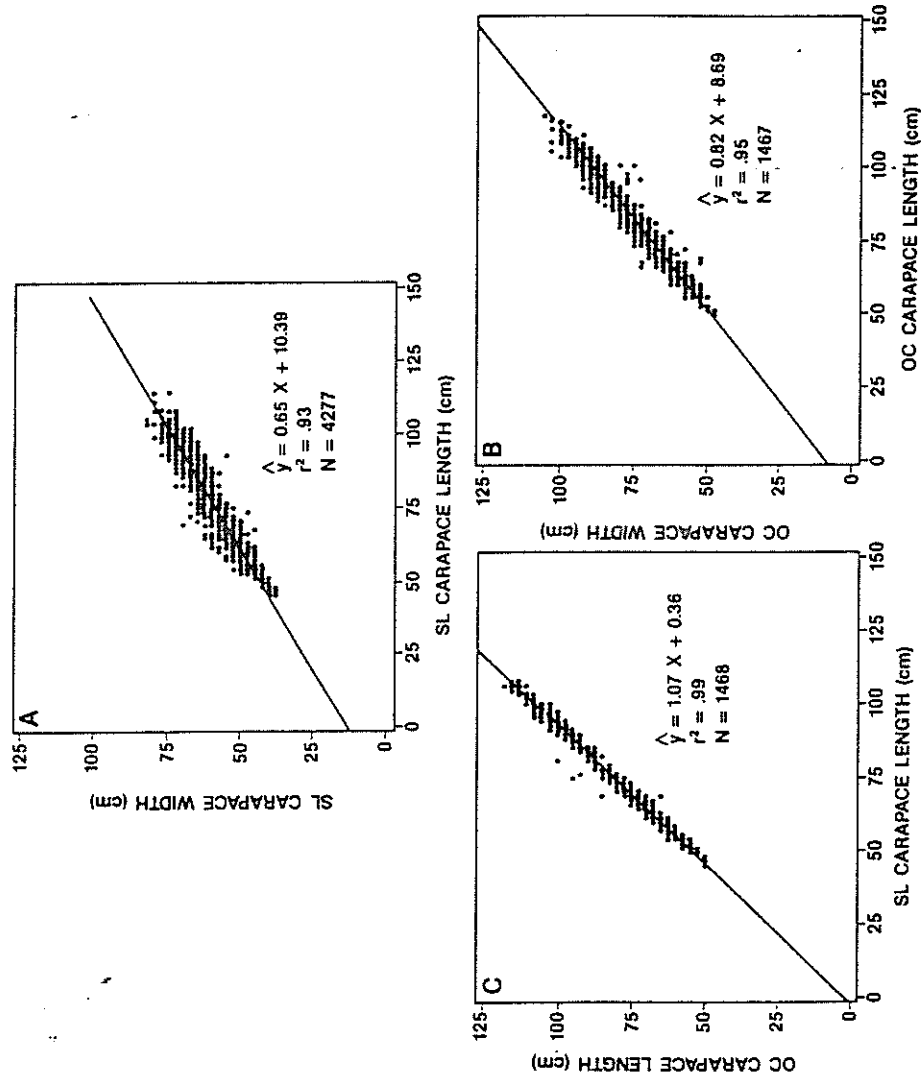


Figure 2. Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (*Caretta caretta*).

of subadults, males and females. Regression of SL carapace width on SL carapace length was performed on each set of animals (Fig. 3A). The slopes of regression equations in both adult male and female turtles were the same, but were significantly different from subadult turtles. For this reason, separate equations for adult turtles and subadult turtles were computed for the remaining cases (Figs. 3B and C).

These analyses indicated that growth in carapace width and OC carapace length (a measure of body depth) was slower in adult turtles than in subadults. Significant differences in the slopes of adult and subadult equations imply that growth in adult turtles was predominantly longitudinal. These findings are in agreement with Uchida (1967), who proposed that growth in loggerhead turtles follows a postero-anterior gradient with greatest growth capacity toward the posterior parts of the animal.

Regressions of weight on SL and OC carapace lengths and widths were best fitted to a power function through log-log transformations (Fig. 4). For both measurement techniques, the weight/length regressions produced higher coefficient of determination (r^2) values than weight/width, an indication that this relationship was the better predictor of the two. Untransformed data were plotted in Figure 4 to demonstrate the curvilinear relationship of length and width to weight. Our computations, however, were based on log-log transformed

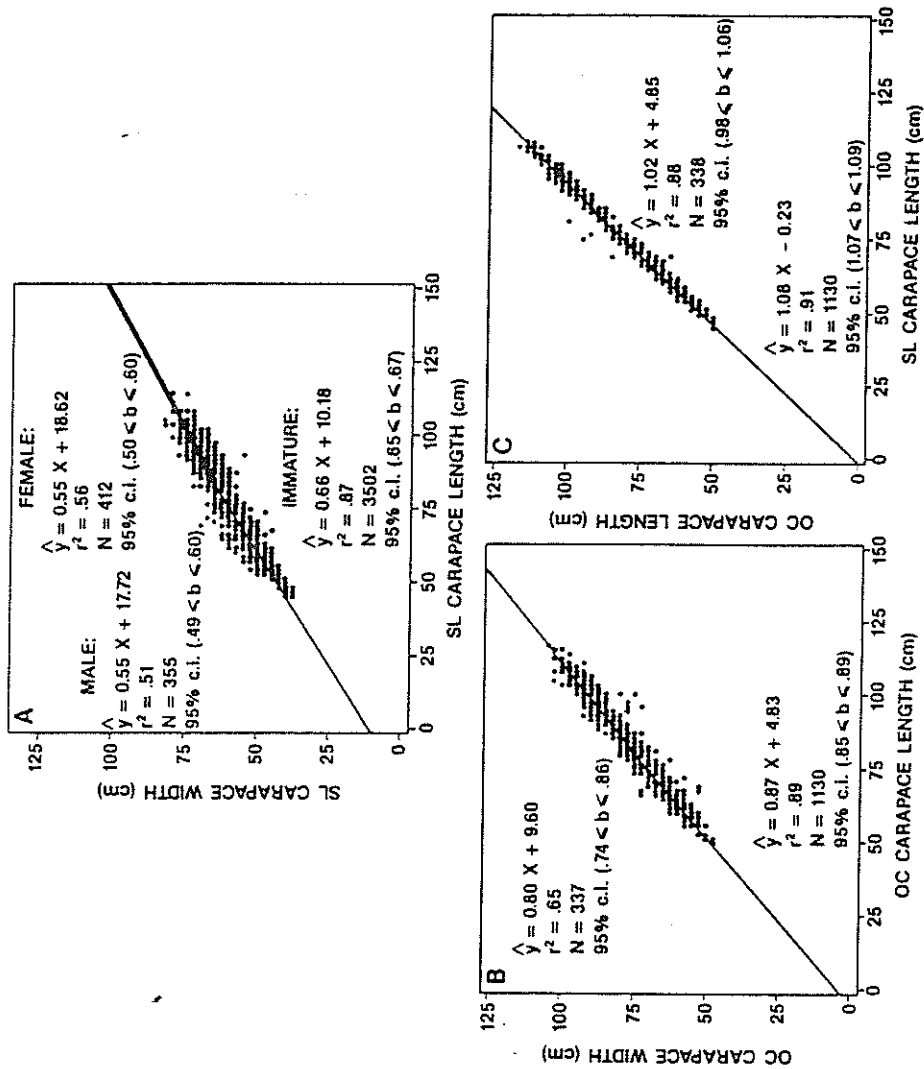


Figure 3. Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (*Caretta caretta*). Adult and subadult regressions computed separately.

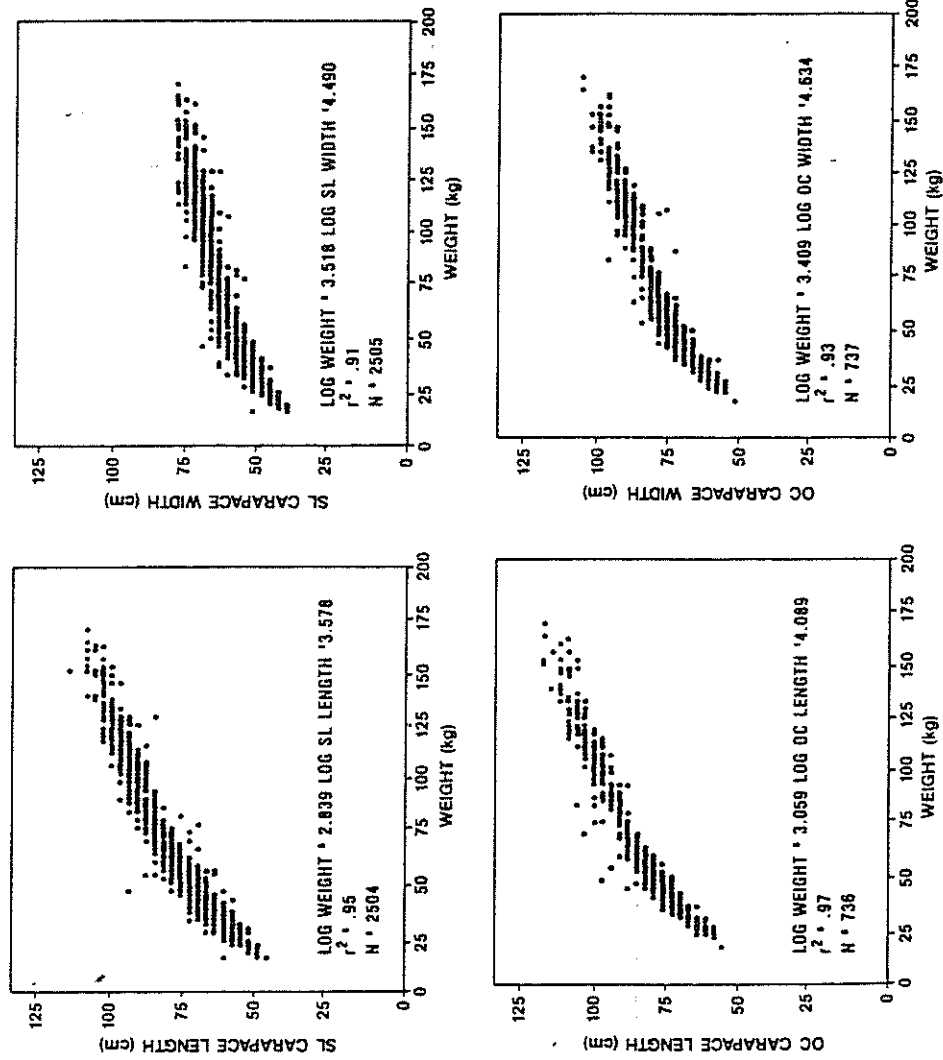


Figure 4. Regressions of straight-line (SL) and over-curve (OC) length and width on weight. Log-log transformed formulae are presented.

data using length and width as the predictor (X) and weight as the response variable (Y).

An examination of the r^2 values from regressions (Figs. 2,3 and 4), revealed that OC measurements were slightly superior to SL measurements as predictors. To test for significant differences in correlation coefficients, OC width on length was compared with SL width on length using Fisher's z transformation (Kleinbaum and Kupper, 1978). The correlation coefficient from OC width on length ($0.976 < r < 0.978$; 95% c.i.) was significantly higher than SL width on length ($0.961 < r < 0.966$; 95% c.i.). While we demonstrated statistically significant differences in this instance, our large sample size resulted in narrow confidence bands. From a practical standpoint, the differences in r^2 values were small; the slight improvement in OC measurements might only be evident in very large samples and be of limited importance in normal application.

The use of tail length as a field method for determining the sex of turtles was appraised with stepwise discriminant analysis techniques. These procedures evaluated how much each variable explained the differences in the sexes and presented the differences as a spatial relationship (Fig. 5). From this plot, it was evident that adult males were well differentiated from the other groups, and that adult females and subadults were separated primarily on the basis of carapace length. Character

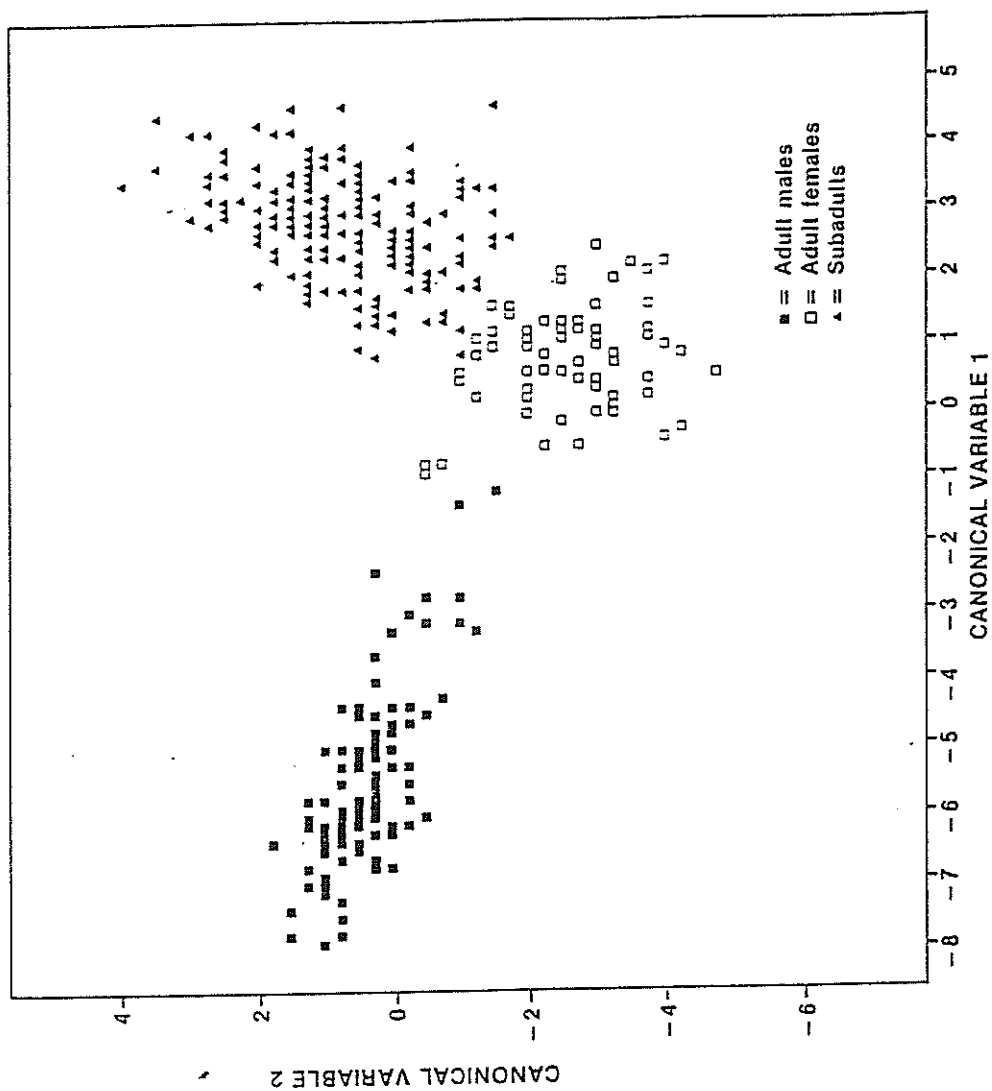


Figure 5. Positions of male, female and subadult loggerhead turtles, *Caretta caretta*, in discriminant space defined by two discriminant functions.

differences among the groups were sufficient to allow correct classification of 96.6 percent of the individuals.

Because our sex identifications were based on visual observations, it was not possible to establish the sex of individuals less than 83 cm total carapace length. Results of discriminant analyses indicated that the tail measurement taken in conjunction with the carapace length measurement is probably an acceptable technique for determining the sex of adult turtles. In subadult turtles, no sexual dimorphism in tail length was evident, nor were there indications that the sex of subadult turtles could be discriminated on the basis of these variables.

Straight-line and over-the-curve measurements of standard, notched and minimum carapace lengths (Fig. 1) were regressed on total carapace length and conversion formulae were derived (Table 1). These conversion formulae are useful for comparisons between studies employing different measurements. An application of these formulae is illustrated in a comparison of several published reports on range and mean size of female loggerhead turtles encountered on U.S. nesting beaches (Table 2). Examination of size of females in separate nesting populations that were measured using three different measurements, indicated a range in means of 90.3 to 95.9 cm (5.6 cm difference). Converting these values to a single measurement (in this case total

Table 1. Conversion formulae for comparisons between different measurement techniques in loggerhead turtles, Caretta caretta.

Measurement calculated	Formula based on length (b)	r^2	N
SL length (a)	$0.9964 \text{ SL length (b)} - 0.775$	0.99	722
OC length (a)	$0.9891 \text{ OC length (b)} - 0.066$	0.99	713
OC length (b)	$1.0700 \text{ SL length (b)} + 0.360$	0.99	1468
SL length (c)	$0.9875 \text{ SL length (b)} - 0.271$	0.99	722
OC length (c)	$0.9680 \text{ OC length (b)} + 1.277$	0.99	712
SL length (d)	$0.9774 \text{ SL length (b)} - 0.809$	0.99	722
OC length (d)	$0.9516 \text{ OC length (b)} + 1.380$	0.99	714

a = Standard carapace length
 b = Total carapace length
 c = Notched carapace length
 d = Minimum carapace length
 OC = Over-the-curve measurement
 SL = Straight-line measurement

Table 2. Comparisons of mean size of nesting female loggerhead turtles, Caretta caretta, of the western Atlantic as reported in the literature.

PUBLICATION AND STUDY LOCATION	NUMBER OF TURTLES	MEAN	MEASUREMENT	MEAN CONVERTED TO TOTAL CARAPACE LENGTH (b)
Ehrhart (1979), Kennedy Space Center, FL	1224	92.5	a	93.6
Ehrhart & Yoder (1978), Merritt Island, FL	194	91.7	a	92.8
Baldwin & Lofton (1959), South Carolina	18	92.7	b	92.7
Caldwell et al. (1959), Jekyll Island, GA	110	95.9	b	95.9
Bjorndal et al. (1983), Melbourne Beach, FL	661	92.0	d	95.0
Gallagher et al. (1972), Hutchinson Is., FL	164	92.5	d	95.5
Worth & Smith (1976), Hutchinson Is., FL	260	90.3	d	93.2

carapace length) reduced the range of means to 3.2 cm, i.e., 92.7 to 95.9 cm.

Mean condition factors by month for subadult and adult loggerhead turtles were computed and results are presented in Table 3. The condition factor (C) for all data ranged from 0.96 to 1.07.

Our results indicated that mean condition factors were similar over all seasons and sizes of turtles (Table 3); however, the highest values occurred during spring and summer months. Lowest values were in the fall and winter seasons when decreased feeding activity and growth were expected. The condition factor (C) best illustrates the seasonality of condition factors in subadult turtles; November to March conditions were lower than 1.0 and with the exception of June, April to October conditions were above 1.0.

DISCUSSION

Results of these investigations have made it possible to describe some relationships in body dimensions of loggerhead turtles. The large quantities of measurement data used in the analyses allow one to discern changes in some morphometric relationships with age, size or stage of sexual development, and to speculate on the significance of these changes to the growth and general biology of turtles.

Table 3. Coefficient of condition (C) in subadult and adult loggerhead turtles, Caretta caretta.

SUBADULTS (<83 CM. TOTAL CARAPACE LENGTH)

Month	Number (N)	Condition Factor (C)	Standard error of the mean (s.e.)
Jan.	79	0.99	0.010
Feb.	181	0.98	0.007
Mar.	276	0.96	0.005
Apr.	32	1.05	0.013
May	47	1.03	0.011
June	44	0.99	0.015
July	99	1.03	0.011
Aug.	196	1.03	0.006
Sept.	231	1.02	0.008
Oct.	280	1.01	0.007
Nov.	478	0.99	0.004
Dec.	73	0.97	0.010
Total	2016	1.00	0.002

ADULTS (>83 CM. TOTAL CARAPACE LENGTH)

Month	Number (N)	Condition Factor (C)	Standard error of the mean (s.e.)
Jan.	2	0.96	0.098
Feb.	57	1.05	0.012
Mar.	72	1.02	0.013
Apr.	74	1.06	0.008
May	68	1.07	0.011
June	34	1.03	0.015
July	36	1.06	0.023
Aug.	28	1.03	0.014
Sept.	22	1.04	0.016
Oct.	35	1.00	0.019
Nov.	53	1.02	0.012
Dec.	7	1.00	0.046
Total	488	1.04	0.004
TOTALS	2504	1.00	0.004

The fact that carapace length, width and body depth relationships differed significantly in adult and subadult turtles indicated that carapace shape changed as turtles matured. These changes were probably gradual and do not reflect an abrupt change in the growth patterns. The observed statistical differences in the slopes of subadult and adult regressions were influenced by our large sample sizes. We speculate that growth in adult turtles may be restricted primarily to the longitudinal axis, while growth in subadults may have larger latitudinal and vertical components.

The regressions of weight on length and width indicated that the weight/length relationship was the better predictor of the two; the length measurement was less variable than the width measurement. This observation supports our contention that turtle growth may continue along the longitudinal axis in adults.

Carr (1952) noted that the shell of male loggerhead turtles appeared narrower or more gradually tapering than the female. In our regressions of SL width on SL length, we observed no differences in this relationship between adult males and females. Our analysis, however, does not preclude the possibility that the shells of males may be more gradually tapering than in females, since width was measured only at the widest point of the shell.

Our analyses of the tail length to carapace length relationship indicated that the sex of subadult turtles cannot be determined on the basis of these feature; the gender of sexually mature males and females can be determined by tail lengths.

A problem with the measurement of tail length from the posterior margin of the plastron to the tip of the tail is the occurrence of supernumerary scutes which protrude posteriorly between or behind the anals. Our measurements were performed from the posterior edge of these supernumerary scutes. Such a non-standard measurement contributes to error, and is one reason why the tail measurement employed is not an acceptable way for sexing subadult turtles.

Carapace length conversions described in this study make possible direct comparisons between studies employing different types of measurements. Our use of SL total carapace length in regressions was based on the fact that this was the standard method used in all NMFS projects. Pritchard et al.(1983) have recommended that standard SL carapace length be adopted as the most appropriate measurement for turtles. Our results indicate that any of these methods are satisfactory, but the use of a single measurement avoids confusion and unnecessary computations in comparing results.

Our purpose in computing condition factors among turtles was not to demonstrate differences in condition of groups of turtles at specific times, but to document the mean and standard errors of condition factors which were encountered over the course of our investigations. The groupings presented in Table 3 were selected arbitrarily and are useful for general trend comparisons only. The condition factor is influenced by sex, season, stage of maturity and size (Everhart et al., 1975), and our preliminary analyses did not separate individuals sufficiently to discern differences in condition based on these variables.

The morphometric relationships presented in this paper are descriptive of loggerhead turtles occurring in nearshore waters of North Carolina to Texas. All of the animals from different areas are treated as members of a single population, and no attempt has been made to separate discrete nesting assemblages. If we could assign subadults to specific nesting assemblages, it might be possible to identify animals of each population on the basis of subtle differences in some morphometric characteristics. To accomplish this, however, a method of identifying subadults from specific nesting populations must be developed.

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V. AGE, GROWTH, SURVIVAL AND MORTALITY IN LOGGERHEAD
TURTLES, CARETTA CARETTA, ESTIMATED FROM
TAG-RECAPTURE EXPERIMENTS

By

Tyrrell A. Henwood

ABSTRACT

Recaptures of previously measured and tagged loggerhead turtles, Caretta caretta, from coastal waters of Florida, Georgia and South Carolina were analyzed to determine growth rates in the wild. Fitting the von Bertalanffy and logistic growth models to loggerhead data, the predictive equation for SL total carapace length at age using the von Bertalanffy equation was determined to be: $L_t = 110.0 (1 - 0.64 e^{-0.0313 t})$. From this equation, age estimates for all loggerhead captures ($N = 4505$) were computed and survival and mortality estimates based on a survival curve were derived. In subadult turtles (13 to 23 years of age), survival and mortality estimates were 0.93 and 0.07,

respectively. In adult turtles (42 to 71 years of age) mean survival rate was 0.92 and mean mortality rate was 0.08.

INTRODUCTION

An important obstacle facing sea turtle researchers is the inability to determine the age of animals. Such knowledge is of critical importance when studying the population dynamics of species. With correct information on age and growth, it is possible to predict longevity, estimate age at maturity, establish critical periods of the life history, determine when habitat requirements change and estimate age specific survival and mortality rates. The need for accurate age determination has been noted (Bustard, 1979; Bjorndal, 1980; Limpus and Walter, 1980; Zug et al., 1983; Zug et al., 1986; Frazer and Ehrhart, 1985), but no validated techniques of aging sea turtles are yet available.

Several researchers have studied growth rates in sea turtles reared in captivity (Parker, 1926; Hildebrand and Hatsell, 1927; Uchida, 1967; Hughes, 1974b; Witham and Futch, 1977; Schwartz, 1981). These studies have provided evidence that turtles are capable of rapid growth under optimal conditions, but their relevance to wild populations is questionable (Gibbons, 1976; Graham, 1979). It has been demonstrated that captive growth rates are dependent on water temperature, quality of food and type of food

administered (Stickney et al., 1973; Wood and Wood, 1981; Naitja and Uchida, 1982). We presently have no means of estimating the growth rates of young turtles in the wild because we have been unable to locate and study these animals or determine the conditions under which growth may be maximized in their natural habitat.

Probably the best method of providing information about age-class changes in wild populations is by marking and releasing individuals of known age and size for later recapture. For sea turtles, direct application of this method is not possible because of our inability to mark hatchlings in a manner that will allow their identification as adults (Bjorndal, 1980), and because small turtles in early life stages do not occur in nearshore habitats and are not represented in our samples. The smallest loggerhead turtles, Caretta caretta, I have encountered in the littoral habitat were at least 45 cm total carapace length and of indeterminate age.

This paper presents estimates of age, growth, survival and mortality in loggerhead turtles, Caretta caretta, based on observed growth rates in subadult and adult turtles. All data were collected during National Marine Fisheries Service (NMFS) sea turtle research in coastal waters of eastern Florida, Georgia and South Carolina from 1978-1984. Growth data were fitted linearly using the geometric mean (GM) functional regression (Ricker, 1975) and nonlinearly to the

von Bertalanffy and logistic growth models. Using these age estimates, survival and mortality rates were calculated.

MATERIALS AND METHODS

All turtles captured during NMFS sea turtle research projects were taken with trawling gear and the following data recorded: location, date, tag identification numbers, species, sex, total carapace length and width, and condition. Nets used in the capture of turtles ranged in size from 12.3-24.6 m headrope length including a wide variety of types and modifications. Turtles were tagged with Monel alloy flipper tags (National Band and Tag Company, Newport, KY) attached to the trailing edge of one or both foreflippers. Straight-line measurements of carapace width and total carapace length (distance from the anteriormost edge of the 1st and 2nd marginals to the posteriormost edge of the 11th or 12th marginals) were taken with calipers. All measurements were converted to metric units for calculations and presentations.

Growth in total carapace length was determined from recaptures of tagged animals. Multiple recoveries of the same turtle were treated as independent events with time elapsed between captures as days-at-large. Only turtles in which original and recapture measurements were performed by NMFS personnel were considered in the analyses to ensure

uniformity in measurement techniques and equipment. Yearly growth rates (Y) were computed for each recaptured turtle using the formula:

$$Y = (C / D) * 365.$$

where

Y = growth over a one year period in cm/yr.

C = difference between initial carapace length and length at recapture.

D = days from initial capture to recapture.

A Ford-Walford plot of carapace length one year after initial capture (initial carapace length + yearly growth) on initial carapace length was constructed and a GM functional regression was used to estimate the asymptotic length (a) and the intrinsic growth rate (k). This has been the most common method of estimating these parameters, but does not consider the variance properties of the estimates. It has been demonstrated (Vaughan and Kanciruk, 1982) that this approach gives biased estimates which are less precise than nonlinear procedures. For this reason, the von Bertalanffy and logistic growth interval equations were fitted to the data with derivative-free nonlinear regression procedures (BMDP, 1979).

Nonlinear techniques were preferable because each interval equation is nonlinear in the parameters a and k.

The primary advantage in using growth interval equations is that only initial length, length at recapture and days-at-large are needed to calculate the parameters. It is not necessary to know the age or the size at birth because the absolute growth rate (dL/dt) is a function of instantaneous size (L) alone, so that the plot of the solution (L vs. t) has constant shape (Schoener and Schoener, 1978). The following growth interval equations (Fabens, 1965) were used for recapture data:

$$\text{von Bertalanffy: } L_r = a - (a - L_c) e^{-kd}$$

$$\text{Logistic: } L_r = aL_c / [L_c + (a - L_c) e^{-kd}]$$

where

L_r = carapace length at recapture

L_c = carapace length at capture

d = time in years between captures

a = asymptotic length

k = intrinsic growth rate

e = base of the natural logarithms

These equations were derived from the general formulae:

$$\text{von Bertalanffy: } L = a (1 - be^{-kt})$$

$$\text{Logistic: } L = a / (1 + be^{-kt})$$

where

t = age in years.

b = parameter related to length at hatching.

The parameter b can be calculated by incorporating the value of a into the equation if the size of turtles at birth is known (Fabens, 1965), or by substitution if length at a particular age is known. Additional discussion of these models can be found in Fabens (1965) and Schoener and Schoener (1978).

Once the age of animals within the population was estimated, survival and mortality rates were computed. A general method for estimating these parameters is by comparing the number of animals alive at successive ages (Ricker 1975). Fitting all loggerhead turtle data ($N = 4505$) to the von Bertalanffy growth equation, age estimates for individuals were computed and frequency of occurrence by age was determined. The natural logarithm of frequency was then plotted by age using running averages of 3 years to smooth the catch curve. The instantaneous mortality rate (Z) and survival rate (S) were calculated using the formulae:

$$Z = -(\text{Log}_e N_{t+1} - \text{Log}_e N_t)$$

$$S = e^{-Z}$$

DATA TREATMENT - BIASES AND ASSUMPTIONS

The original data base consisted of 455 recaptures from which yearly growth rates were computed and plotted (Fig. 1). To determine the error associated with these estimates, measurements of turtles recaptured over periods of less than 30 days (N=188) were compared with original measurements. This approach assumes little or no growth occurred over short time periods and that data can be treated as replicate measurements of the same animal. Results indicated a mean change in length of $0.150 \text{ cm} \pm 0.9359$ (95% confidence interval), a measurement error of approximately $\pm 1 \text{ cm}$.

Another consideration in examining this plot is the effects of extrapolating growth rates over short time periods to yearly growth rates. It is evident that largest positive and negative growth rates were computed for the shortest periods at large. Outside the scale of this plot were 78 positive yearly growth estimates ranging from 10 to 742 cm/yr and 37 negative estimates ranging from -10 to -464 cm/yr. All extreme values occurred over days-at-large periods of less than 90 days.

Considering the effects of extrapolating observed changes in length to yearly growth rates and the error associated with measurements, a large portion of the data set were excluded from subsequent analyses. All recaptures over days-at-large periods of less than 90 days (N = 280)



Figure 1. Computed yearly growth (cm/yr) plotted on days-at-large in loggerhead turtles, Caretta caretta.

and all remaining negative growth rates ($N = 57$) were removed. The resultant data set consisted of 118 records.

From a statistical standpoint, the exclusion of data points less than 90 days-at-large should not bias results since all points were removed. The exclusion of negative data points, however, introduces a bias which may result in an overestimation of true growth rates. The decision to remove these points despite the known biasing effect was based on biological considerations. While growth rates in turtles are undoubtedly subject to fluctuations, these changes are probably reflected in the weight of the animal and not in the carapace dimensions. Shrinkage of hard parts in turtles does not seem likely. The inclusion of negative data in the analyses would, therefore, incorporate data points I believe to be incorrect and which I attribute to measurement error.

The retention of all positive data points when negative data were excluded is questionable, because an equal number of overestimates would be expected in normal measurement error. I chose to retain all positive data because I assumed that any positive growth rates might be possible, while negative growth was impossible. Had I eliminated the largest 57 growth increments along with negative data points, my results would have been negatively biased by what I believe to be unrealistic data and some real positive growth increments would have been lost. For this reason, my

results must be considered to represent growth rates equal to, or in excess of, the true mean for loggerhead turtles.

In catch curve analyses, a major hidden assumption in interpreting the straightness of the right limb is that population age distribution is stable. If gaps in the size/age distribution represent missing age classes due to some past disaster, these gaps will move through the population as turtles grow thus violating this assumption. My interpretation of the data was that gaps in the distribution resulted from incomplete sampling of specific age classes.

RESULTS

Age and Growth

Fitting loggerhead data to the von Bertalanffy and logistic growth models using nonlinear regression techniques, the parameters a and k were estimated (Table 1). Based on the recommendations of Dunham (1978), the von Bertalanffy model was determined to be the more appropriate of the two models because it had slightly lower residual mean squares.

The parameter b was first calculated by substituting a known hatchling size of 4.5 cm into the equations. The plot of total carapace length on age (Fig. 2), suggested that turtle growth was slow and longevity high. Considering the

Table 1. Asymptotic estimates of parameters a and k with standard errors for non-linear regression of logistic and von Bertalanffy equations and GM linear regression of the von Bertalanffy equation. The GM linear regression (Ford-Walford plot) is probably least appropriate because the independent variable is not measured without error.

Parameter	a	k

von Bertalanffy (GM linear regression)	110.790	0.0404
Lt = 110.790 (1 - be ^{-0.0404t})		
Residual mean square error = 2.1640		

von Bertalanffy (non-linear regression)	110.002	0.0313
Lt = 110.002 (1 - be ^{-0.0313t})		
Asymptotic standard deviation	14.722	0.0123
Residual mean square error = 1.337		

Logistic (non-linear regression)	109.756	0.0478
Lt = 109.756 / 1 + be ^{-0.0478t}		
Asymptotic standard deviations	11.802	0.0110
Residual mean square error = 1.395		

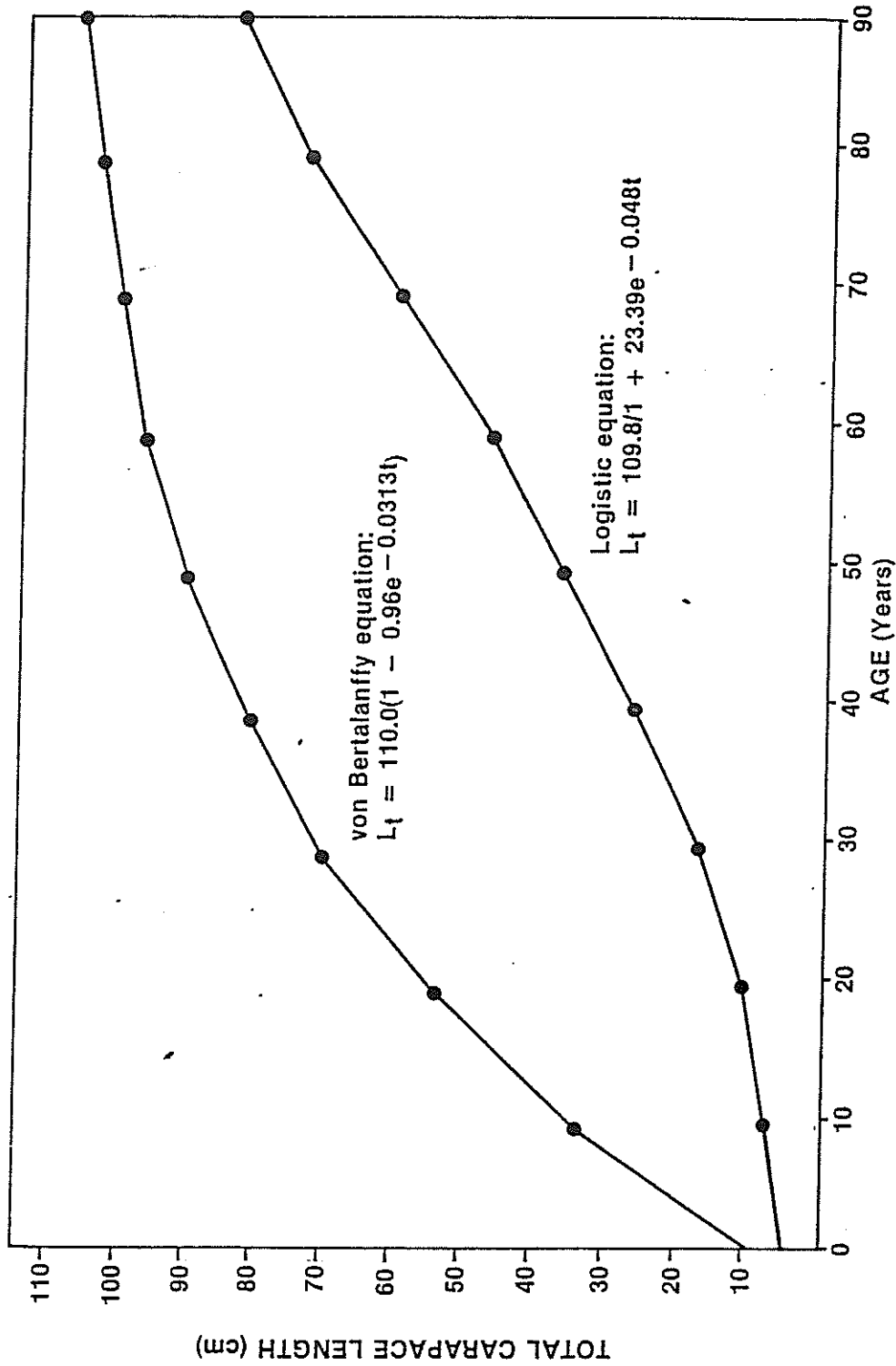


Figure 2. Age/size estimates for loggerhead turtles, *Caretta caretta*, fitting the von Bertalanffy and logistic models to tag-recapture data using a known hatchling size of 4.5 cm.

fact that 97% (114 of 118) of the data points were in the 50 to 90 cm range where the von Bertalanffy and logistic curves were similar in shape, the major portion of each curve was fitted assuming that turtles had always grown in the manner described by the equations (Ricker 1975). This assumption did not appear realistic because age estimates at recruitment to the littoral habitat were high (19 years for the von Bertalanffy and 62 years for the logistic equation). In contrast, results of most captive growth studies have estimated the age of a 50 cm loggerhead turtle at from 3 to 4 years (Fig. 3).

The parameter b was then recomputed to reflect an assumed age of 5 years at 50 cm carapace length (Fig. 3). Based on this equation, assuming that the smallest nesting female loggerhead is 74 cm carapace length and the mean nesting size is 92 cm carapace length (Ehrhart, 1980), I estimated that sexual maturity may be reached at 22 years of age with a mean age of nesting females of approximately 44 years. The subadult stage of life (50 to 75 cm total carapace length) encompasses a period of over 15 years.

Survival and Mortality

The catch curve of the natural logarithm of frequency on age indicated that age distributions were bimodal with peak frequencies of occurrence at ages 13 and 42 (Fig 4). This situation was different from the 'classical' catch

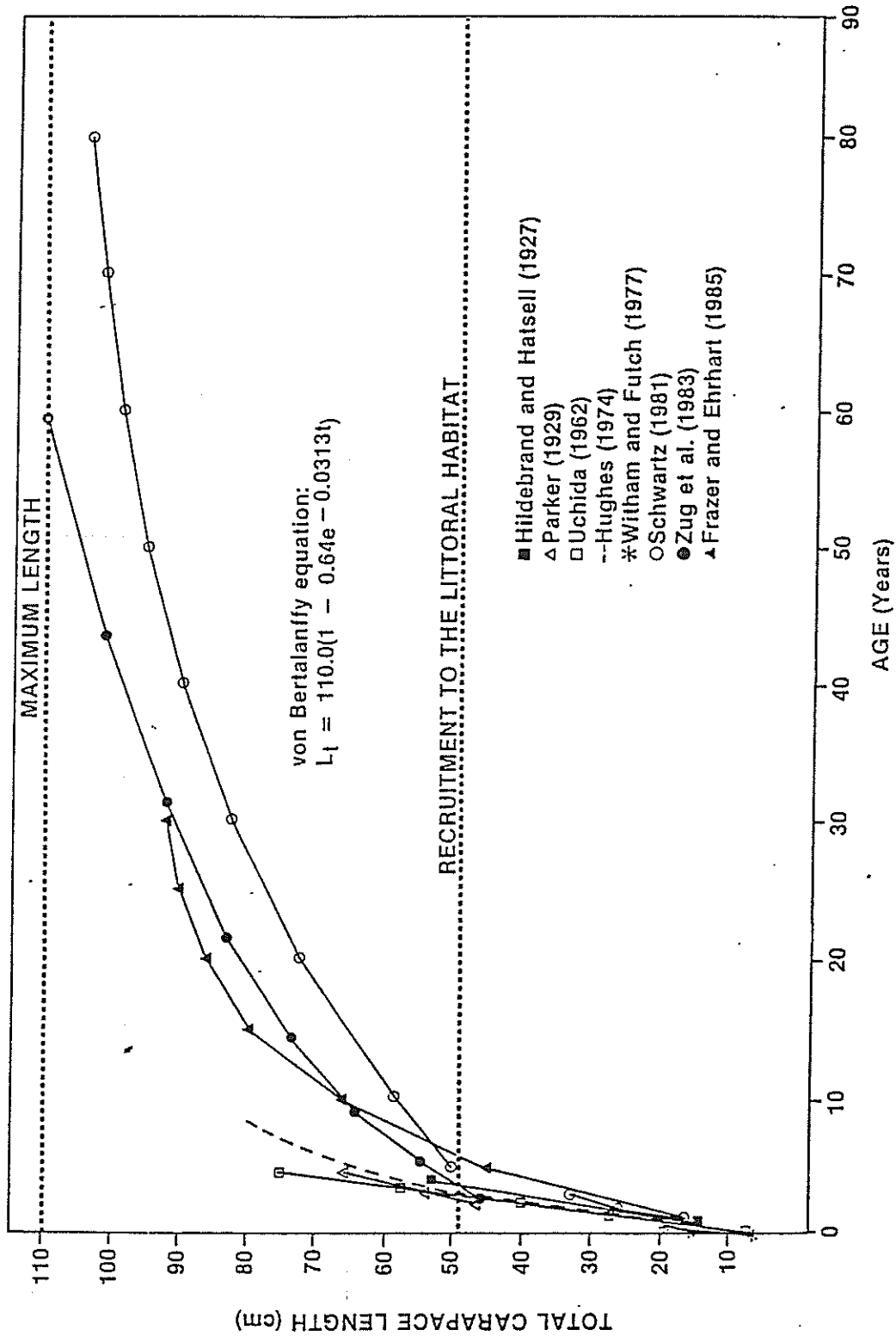


Figure 3. Age/size estimates for loggerhead turtles, *Caretta caretta*, fitting the von Bertalanffy model to tag-recapture data using an assumed age of five years at 50 cm. Other age/size estimates are presented for comparison.

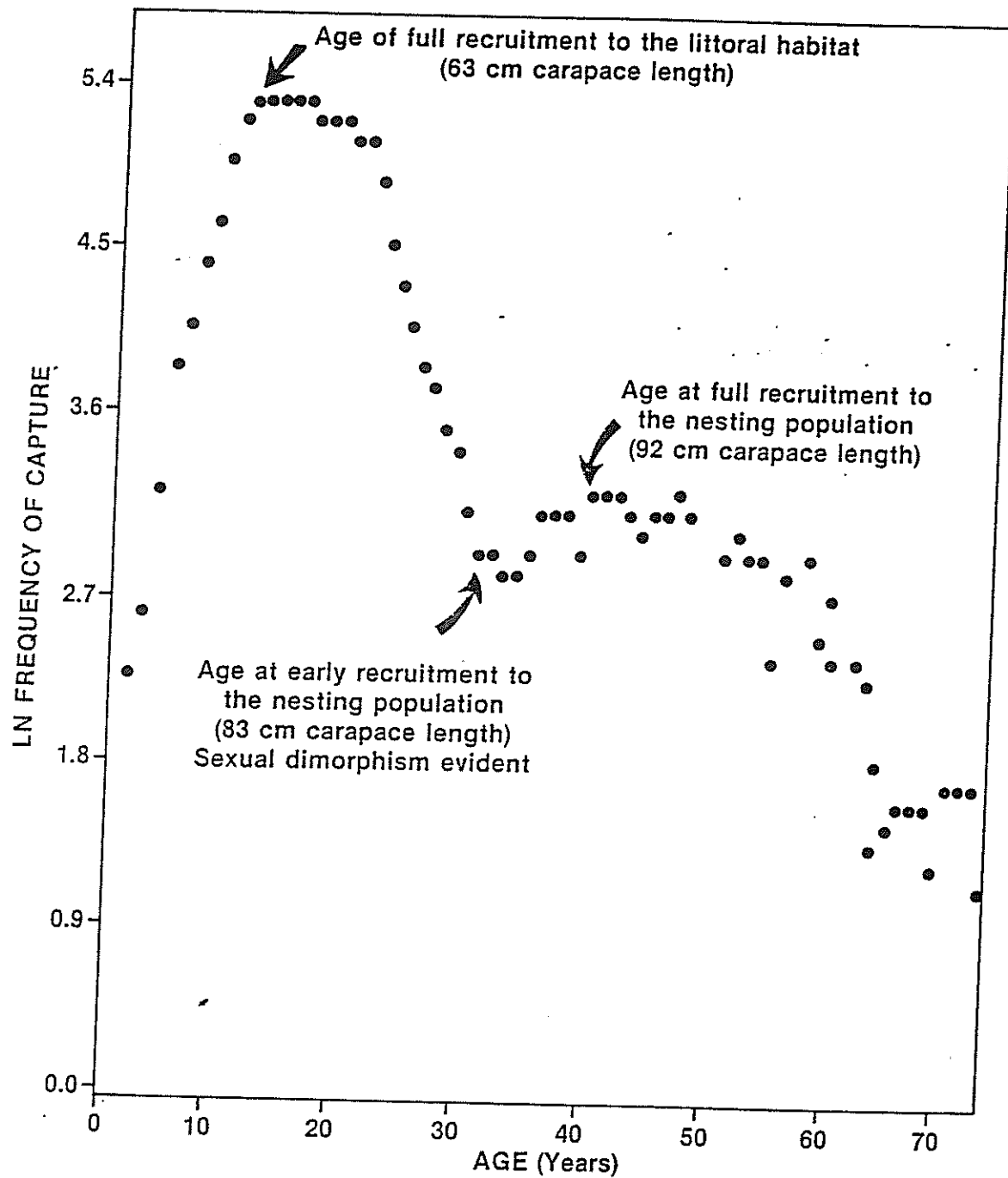


Figure 4. Catch curve of natural logarithm of frequency on age in loggerhead turtles, *Caretta caretta*, using running averages of three years.

curve in which the descending right limb is more or less straight indicating uniform survival with age. The shape of the curve does not preclude the possibility that survival was uniform, but it suggests that certain age classes were not adequately represented in the samples. Two possible explanations for the reduced number of individuals in ages 24-41 could be differential mortality on these year classes or different habitat preferences during these ages.

In computing the survival rate for loggerhead turtles, two sections of the catch curve were utilized. The first estimate was based on computed mortality rates in turtles from age 13 (age at full recruitment to the littoral habitat) through age 23. Over this 10 year period, the mean yearly mortality rate (Z) equalled 0.07 and the mean survival rate (S) equalled 0.93. The second survival estimate was based on mean mortality rates in turtles from 42 years of age (age at full recruitment to the breeding population) through age 71. The mean yearly mortality rate in this group was 0.08 with a mean survival rate of 0.92.

DISCUSSION

Age and Growth

In some fish populations, discontinuities in growth patterns occur when recruits migrate from nursery grounds to the main exploited area and commence feeding on different

types and abundance of food (Beverton and Holt, 1957). In loggerhead turtles, a change in growth patterns may occur when turtles migrate to the littoral habitat. This change in the growth pattern would not affect the validity of the von Bertalanffy equation above 50 cm. The fact that it may not give a true representation of growth during the pre-recruitment phase is unimportant when dealing with exploitation in the post-recruitment phase (Beverton and Holt, 1957). In the present analyses, the assignment of age 5 years at 50 cm assumed that growth patterns changed at the time of recruitment to the littoral habitat, and that pre-recruitment growth rates approached captive growth rates. The rationale for this assumption is discussed in the following paragraphs.

There are a number of reasons why captive growth studies may overestimate growth in wild sea turtles. The main objection to using captive growth studies in predicting wild growth rates is the fact that captive animals usually are subject to conditions thought to optimize growth. Turtles reared in captivity are generally held under constant temperatures and fed high protein foods. Little energy is expended in food gathering or escaping predation, and growth should be maximized. Another objection to use of captive growth information is that most captive rearing programs only record growth from hatchling to the age of one year, when growth is thought to be maximal.

While these objections are valid, the assumption that wild turtles are subject to less than optimal conditions during the presumed pelagic existence is unsubstantiated. Carr (1986) has presented some convincing arguments that pelagic turtles may be associated with areas of convergence, where downwelling concentrates food resources and aligns debris that provides concealment. Carr (1986) further suggests that pelagic turtles may be passively transported in the North Atlantic Gyre, circling in this gyre as part of their normal development. Loggerhead growth during this developmental stage conceivably could be maximal, assuming constant food availability and moderate temperature fluctuations.

There are also some valid reasons why extension of the von Bertalanffy curve through hatchling size may underestimate growth rates in very young turtles. From an ecological standpoint, the littoral environment is much less stable than the pelagic, and animals occurring in this habitat are subject to temporal and spatial fluctuations in foraging opportunities and temperature. Changing conditions may result in periods of maximal growth followed by periods of little or no growth. Conversely, the pelagic environment is less subject to fluctuations, and may offer more stable temperatures and consistent foraging opportunities which could maximize growth rates.

Another reason that extrapolation of the von Bertalanffy curve may underestimate growth in young turtles is the fact that growth in carapace length may be accelerated during the early years of life. Since no data on growth rates in small turtles were incorporated in the models, growth rates during early growth stanzas were estimated assuming that animals had always grown in the same manner as subadults in the littoral habitat.

A final argument in favor of shifting the von Bertalanffy curve to age 5 at 50 cm is the survival considerations associated with a protracted pelagic existence and slow growth. Hatchling turtles are subject to extreme predation levels while in the nests and upon emergence from nests and entrance to the sea. Rapid growth during the early months at sea would impart survival advantages to the species, possibly by allowing turtles to achieve a size refuge beyond which predation is greatly reduced. In this manner, turtles reaching a large enough size would be relatively immune to predation by birds and fish, and could devote additional energies to feeding and growth. Conversely, slow growing turtles would be subject to continuous pressures over several years, and the survival potential would be reduced.

Comparisons with Other Age Estimates

Age estimates at sexual maturity in loggerhead turtles have ranged from 6-7 years (Uchida, 1967; Caldwell, 1962) to

30-50 years (Limpus, 1979). In general, captive growth studies have predicted rapid growth, while tag/recapture studies have suggested slower growth rates and increased longevity.

Three recent papers (Mendonca, 1981; Frazer and Ehrhart, 1985; and Zug et al., 1986) have estimated the age at sexual maturity in loggerhead turtles from Florida and Georgia. These estimates were 10-15 years, 12-30 years and 13-15 years, respectively. Mendonca (1981) and Frazer and Ehrhart (1985) based their estimates on some of the same tag/recapture information, while Zug et al. (1986) estimated age on the basis of incremental growth rings in the skeleton. Mendonca (1981) used 74 cm straight-line carapace length (CL) and Zug et al. (1986) used 80 cm curved carapace length (size of the smallest female observed nesting on Florida beaches) as the size at sexual maturity, while Frazer and Ehrhart (1985) suggested that a somewhat better estimate of age at sexual maturity was the mean size of nesting turtles which was approximately 92 cm.

A comparison of my results with those of Mendonca (1981) indicated that turtles in her study area (Mosquito Lagoon, FL) exhibited faster growth. Mendonca's mean growth rate (5.90 cm/yr, N=13) was more than three times the mean growth rate (1.62 cm/yr, N=118) observed in this study. These differences may be related to Mendonca's small sample size, possible bias in her data treatment (Frazer and

Ehrhart, 1985) or time periods over which growth was measured. They may also reflect real differences in loggerhead growth rates in lagoonal systems.

Frazer and Ehrhart (1985) used only 8 of Mendonca's 13 data points along with 20 measurements of growth in adult female loggerheads, and predicted slower growth rates than Mendonca (1981). Their estimates of growth rates, however, were larger than those observed in this study.

In comparing age estimates with those of Zug et al. (1986), the formula ($\log Y = \log 1.0 \times 10^{-9} + 3.498 \log X$) was used to plot age (Y) from over-the-curve CL (George Zug, Smithsonian Institution, pers. comm.). Length at age was then converted to straight-line CL using the conversion formula of Henwood and Moulding (in preparation). Zug et al. (1986) predicted an age of 13 to 15 years at sexual maturity, while my estimates for a 74 cm turtle were from 20 to 23 years.

It is worthy of note that using the estimates of a and k derived from the GM linear regression and adjusting the resultant von Bertalanffy equation to reflect age 4 years at 50 cm [$L_t = 110.8 (1 - 0.64 e^{-0.0404t})$], the growth curve is virtually the same as Zug et al. (1983). This is apparently coincidental, but illustrates the agreement of our independently derived estimates which were based on different techniques and analytical procedures.

Age estimates were in closest agreement with those of Limpus (1979) for loggerhead turtles in Australian waters. His estimates of 30 to 50 years at sexual maturity encompass my estimate of mean nesting age (44 years).

Survival and Mortality

The first consideration in evaluating the catch curve was the possibility that sampling bias or gear selectivity may have resulted in disproportionate sampling of the population. Gear selectivity does not appear likely since turtles over all size ranges were captured. There were no reasons to assume that sampling was not random or that age groups were not sampled in proportion to their actual abundance. One possible source of sampling bias was the fact that Cape Canaveral and most shrimping grounds were in close proximity to nesting beaches, and breeding adults may have been captured in numbers exceeding their true proportional abundance in the population. To test for disproportionate sampling, the number of individuals at age 13 were extrapolated to the number of individuals expected to be present at age 42 assuming a constant survival rate of 0.94. The calculated number of individuals was 40, and the actual count was 36 indicating that breeding adults were probably sampled in proportion to their true abundance. It was concluded that the reduced number of individuals in the age 24-41 range cannot be explained by disproportionate sampling of adults.

Another possible explanation for the reduced number of individuals from age 24-41 was selective mortality on these age classes. High mortality rates over a protracted time period (17 years) were probably not related to natural causes. The most likely source of such mortality was through activities of man, primarily commercial or incidental capture by fishermen.

With the passage of the Endangered Species Act in 1973, sea turtles have been protected both on land and at sea. Assuming that the catch curve approximated true population structure in 1982 (mean year of our sampling), animals from age 13-23 reflect natural survival rates since protective measures were instituted. These animals would have been age 4-14 in 1973, and would have been least vulnerable to harvesting during the preceding years. Turtles from ages 24-41 would have been 15-32 years of age in 1973, and would have been the most vulnerable year classes from 1956-1973. Considering the increases in number of fishing vessels and the efficiency of these vessels, increased turtle mortalities over this time period might be expected.

Another explanation for the structure of the catch curve was a change in habitat coinciding with the onset of sexual maturity. Turtles recruiting to breeding populations may vacate inshore areas and move to offshore habitats. This situation could account for reductions in number of individuals in the 24-41 age groups.

To further examine this possibility, the natural logarithm of frequency of adult females and adult males were plotted on the original catch curve (Fig. 5). This plot suggests that males recruit to the breeding populations at older ages (increased size) than females, and that small male turtles rarely occurred in the samples. Differential habitat preferences of developing males would explain the reductions in number of individuals in the 24-41 age groups, since these animals would not have been captured in our samples.

Frazer (1983) estimated survivorship of adult female loggerhead turtles nesting on Little Cumberland Island, Georgia based on a 20-year tagging study. Using a totally different method, he estimated that annual survivorship was constant at 81 percent and the maximum reproductive life span was 32 years. These findings are in reasonable agreement with my results; the major difference being his lower estimates of survival which result in lower estimates of the life span.

CONCLUSIONS

Growth in wild loggerhead turtles (50 to 110 cm carapace length) fits the von Bertalanffy growth model quite

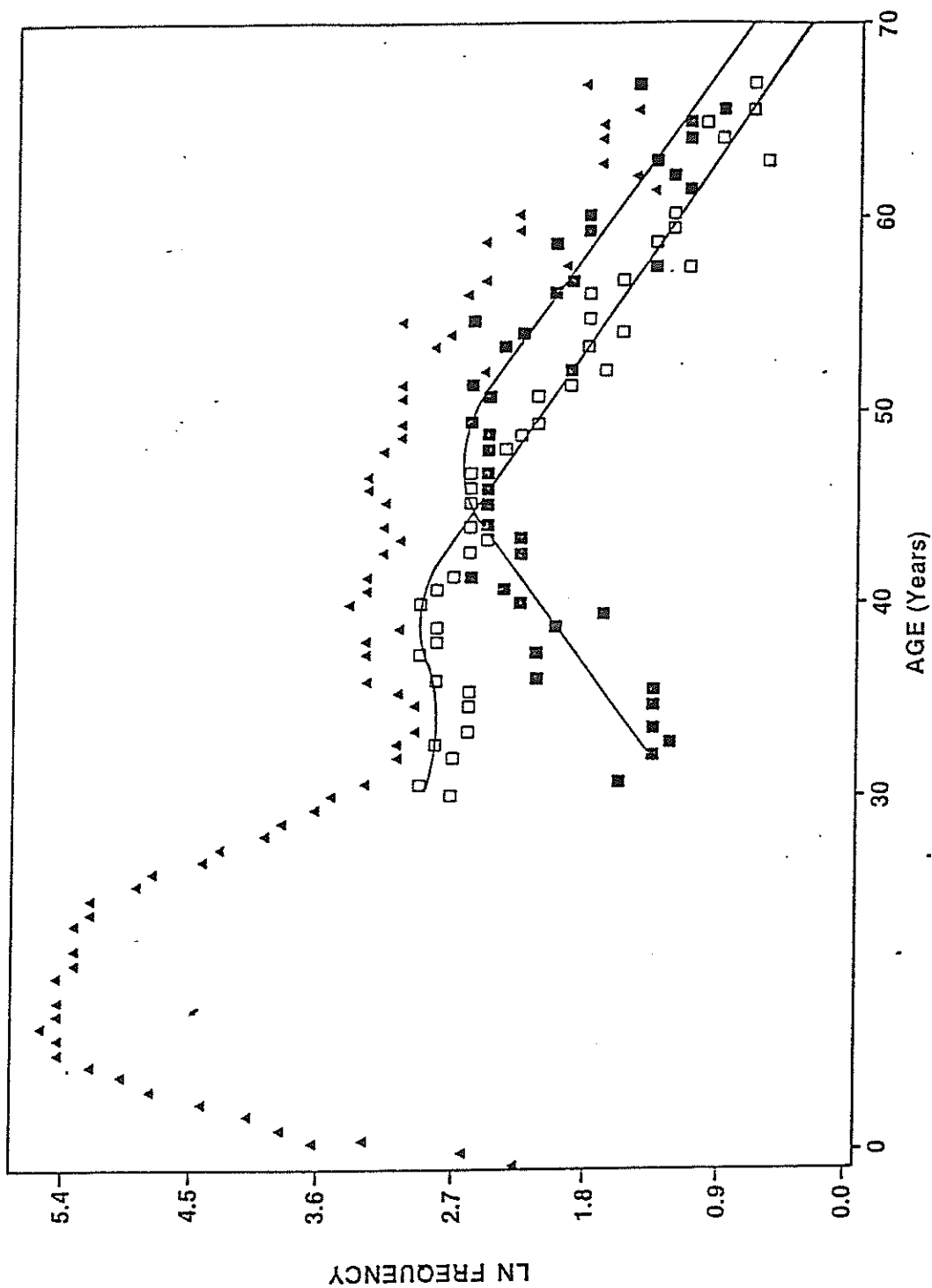


Figure 5. Catch curve of natural logarithm of frequency on age in loggerhead turtles, Caretta caretta. All turtles (Δ), adult males (\blacksquare) and adult females (\square) are plotted separately.

well. In turtles smaller than 50 cm, growth projections were unrealistically slow suggesting that growth patterns during the developmental stage prior to recruitment to the littoral zone may be different from those observed in the littoral habitat. For this reason, the von Bertalanffy equation was shifted to reflect an assumed age of 5 years at 50 cm. The predictive equation for SL total carapace length at age in turtles greater than 50 cm is: $L_t = 110.0 (1 - 0.64 e^{-0.0313t})$.

Using this formula, mean survival and mortality estimates in subadult turtles (13 to 23 years of age) were determined to be 0.94 and 0.07, respectively. In adult turtles (42 to 71 years of age) mean survival rate was 0.92 and mean mortality rate estimated at 0.08. Turtles aged 21 to 41 years were not represented in the sample at their expected abundance, and this reduction in number of individuals may be related to differential habitat preferences in male turtles nearing sexual maturity.

These analyses, while preliminary in nature and based on several assumptions, represent the largest data base on wild growth rates assembled to date. The good fit of the data to the von Bertalanffy growth model in sizes 50 to 90 cm suggests that growth patterns in loggerhead turtles may conform to this model after recruitment to the littoral habitat. Growth during pre-recruitment stages, however, apparently does not conform to the model and remains to be

determined. Once growth rates during this developmental stage have been determined, the equation can be shifted to reflect the true age at recruitment to the littoral habitat.

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VI. MOVEMENTS AND SEASONAL CHANGES IN LOGGERHEAD TURTLE,
CARETTA CARETTA, AGGREGATIONS IN THE VICINITY OF
CAPE CANAVERAL, FLORIDA (1978-1983)

By

Tyrrell A. Henwood

ABSTRACT

Capture records from loggerhead turtles, Caretta caretta, tagged in the vicinity of Cape Canaveral, Florida (1978 to 1983) were analyzed to determine seasonal distributions and movement patterns. Three distinct groups of turtles (adult males, adult females and subadults) occurred in the study area, and each was dominant at different times of the year. Adult males were most abundant in April and May, adult females were most common from May through July, and subadults constituted over 80% of the population during the remainder of the year. Separate treatment of the three groups was necessary, because movement of one group into the area was apparently correlated with the emigration of the remaining two. The data suggest that nesting females are short-term residents

who migrate into the area on two and three year intervals and reside elsewhere during non-nesting years. Adult male turtles apparently do not migrate with the females, but may reside in the vicinity of nesting beaches throughout the year. Subadult turtles forage opportunistically along the Atlantic seaboard, possibly moving northward as waters warm in the higher latitudes and southward with the onset of winter. Evidence suggests that a resident population of subadults overwinter in the Canaveral area each year.

INTRODUCTION

In the western Atlantic, loggerhead turtles, Caretta caretta, occur throughout the Gulf of Mexico and the Caribbean Sea northward to Nova Scotia (Carr, 1952). Seasonally, loggerheads are common as far north as the Canadian portions of the Gulf of Maine (Lazell, 1980) but during cooler months of the year distributions shift to the south (Shoop et al., 1981). Aerial surveys of loggerhead turtles at sea indicate that they are common in waters less than 50 m depth (Shoop et al., 1981; Fritts et al., 1983) but occur pelagically as well. Shoop et al. (1981) speculated that turtles sighted in deep oceanic waters were probably in transit to other areas.

While the occurrence of loggerheads in coastal waters has been well documented, little information on the

movements of these turtles is available. Several researchers have analyzed movements of adult female loggerhead turtles from recoveries of turtles tagged on nesting beaches (Caldwell et al., 1959; Caldwell, 1962; Bustard and Limpus, 1971; Hughes, 1974a; Bell and Richardson, 1978; Ehrhart, 1979; Meylan and Bjorndal, 1983). In general, these studies indicate that turtles may travel considerable distances, but direction and rate of dispersal appears inconsistent. Bell and Richardson (1978) and Hughes (1974a) have suggested possible migratory routes followed by post-nesting female turtles, but evidence for these movements is based on a limited number of tag recoveries and remains inconclusive.

Researchers need information on the distributions and movements of turtles and groups of turtles to effectively manage and conserve stocks. At the present time, virtually no data are available from the time hatchlings enter the sea until female turtles return to the natal nesting beaches. In particular, subadult turtles and adult male turtles have seldom been studied because they must be captured and tagged at sea, a costly and time consuming process. The discovery of large concentrations of turtles in the Port Canaveral, FL ship channel (Carr et al., 1980) has made the use of trawling gear effective in this locality, thus permitting the capture and tagging of subadult and adult male turtles in addition to adult females.

Presented are results of continuing studies of loggerhead turtle aggregations in the Cape Canaveral, FL area. Turtles utilizing this unique habitat are primarily subadults, but during nesting season the population shifts to an adult dominated assemblage. Recaptures of turtles tagged in the Canaveral area were analyzed to determine movement patterns of adult male, adult female and subadult turtles. These studies were conducted as part of the National Marine Fisheries Service (NMFS) Endangered Species Program in accordance with the Endangered Species Act 1973-16 USC 1531-1543.

MATERIALS AND METHODS

Tagging records from five NMFS sea turtle research projects were used in analyses. Although objectives and sampling methodologies of each project differed, all used trawling gear to capture turtles, and each project recorded similar capture data: location, date, tag identification numbers, species, sex, total carapace length and width, and condition of captured animals. Nets used in the capture of sea turtles ranged in size from 12.3-24.6 m headrope length, including a wide variety of types and modifications. All turtles were tagged with Monel alloy flipper tags (National Band and Tag Company, Newport, KT) attached to the trailing

edge of one or both foreflippers. Tag returns were obtained opportunistically from NMFS projects, commercial shrimp fishermen, gill net fishermen, surf anglers, beach strandings, power plants, and turtle researchers monitoring nesting beaches.

For the present analyses, only turtle captures in the Cape Canaveral ship channel and adjacent waters ($28^{\circ} 15'N$ to $28^{\circ} 30'N$ latitude) were considered (Fig.1). Recaptures of turtles initially tagged in the study area but recovered elsewhere, were included for analysis of long-distance movement patterns.

To characterize turtle aggregations in the Cape Canaveral area, turtle capture data were pooled and frequency of occurrence by total carapace length plotted. From this plot it was evident that size distributions were bimodal. To establish the points of inflection of the two distributions, length frequencies were plotted on probability paper according to methods described in Cassie (1954).

To determine if size and sex composition of turtle aggregations changed over the course of the year, data were pooled over all years, separated by month and composition (adult males, adult females and subadults) analyzed with a Chi-square test for independence. Percent composition of the groups was plotted by month to illustrate monthly changes in Canaveral turtle aggregations.

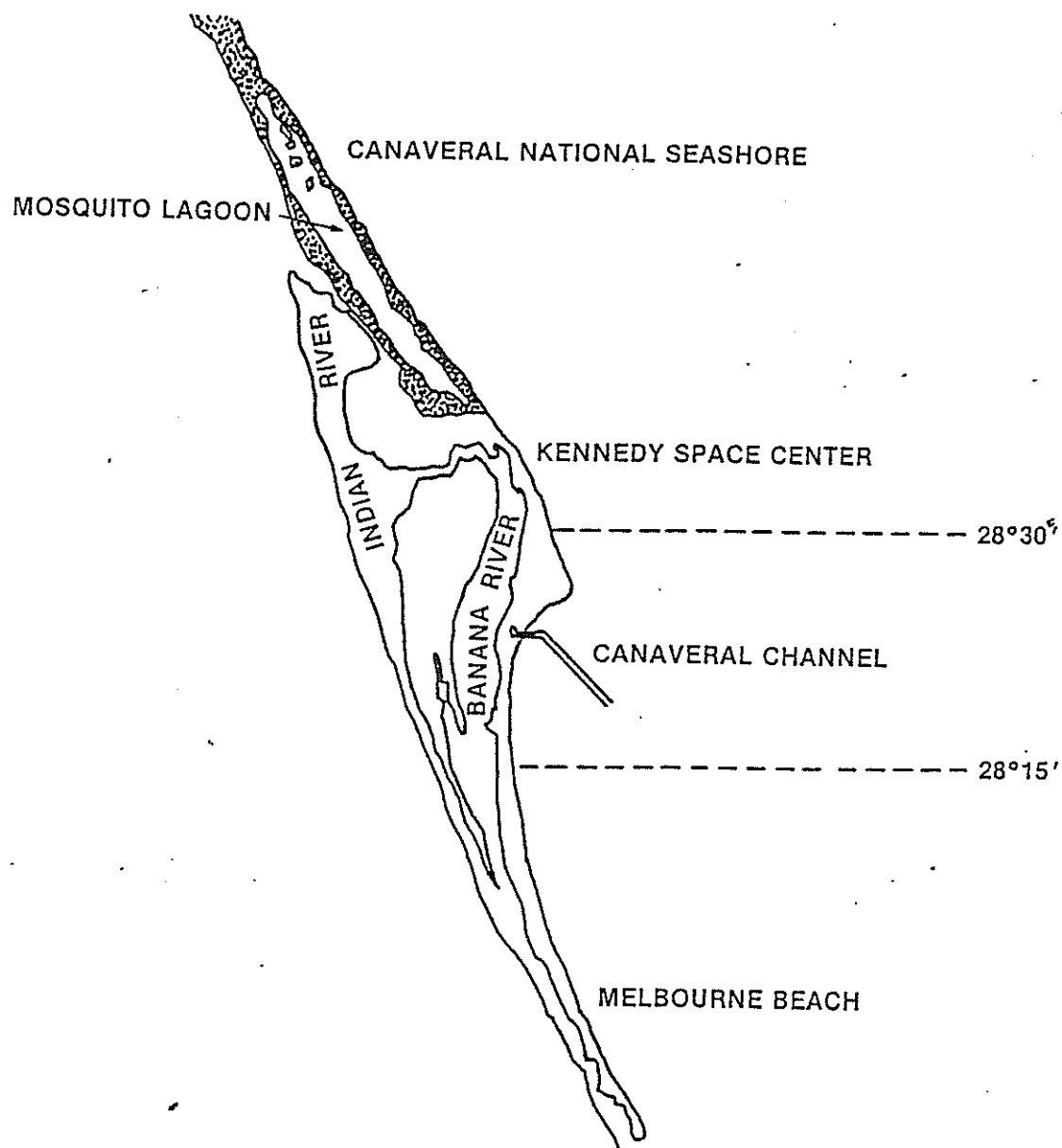


Figure 1. Description of the primary study area including local nesting beaches at Canaveral National Seashore, Kennedy Space Center and Melbourne Beach.

An unusual opportunity to monitor daily and weekly changes in turtles of the Canaveral area occurred during sea turtle rescue operations from July through December, 1980. This effort, conducted jointly by the U.S. Army Corps of Engineers (COE) and NMFS was undertaken to capture and relocate sea turtles from the Cape Canaveral ship channel prior to dredging. Over a 132-day period, 91 days of trawling were conducted, thus providing a chance to study day-to-day movements of turtles.

RESULTS

Of the loggerhead turtles captured in the study area (including recaptures) eighty-two percent (3021 of 3710) were subadults, nine percent (349 of 3710) were adult females and nine percent (340 of 3710) were adult males. These totals represent 3132 individuals: 2546 subadults, 271 adult females and 315 adult males.

The plots of frequency of capture by total carapace length (Fig. 2) and of length frequencies by cumulative percent (Fig. 3) indicated that two size groups of turtles inhabit the Canaveral area. An assemblage of smaller animals (mean carapace length = 69 cm) comprises 83 percent of the total captures, and a group of adult turtles (mean carapace length = 95 cm) make up the remaining 17 percent of the captures. These findings are in agreement with size

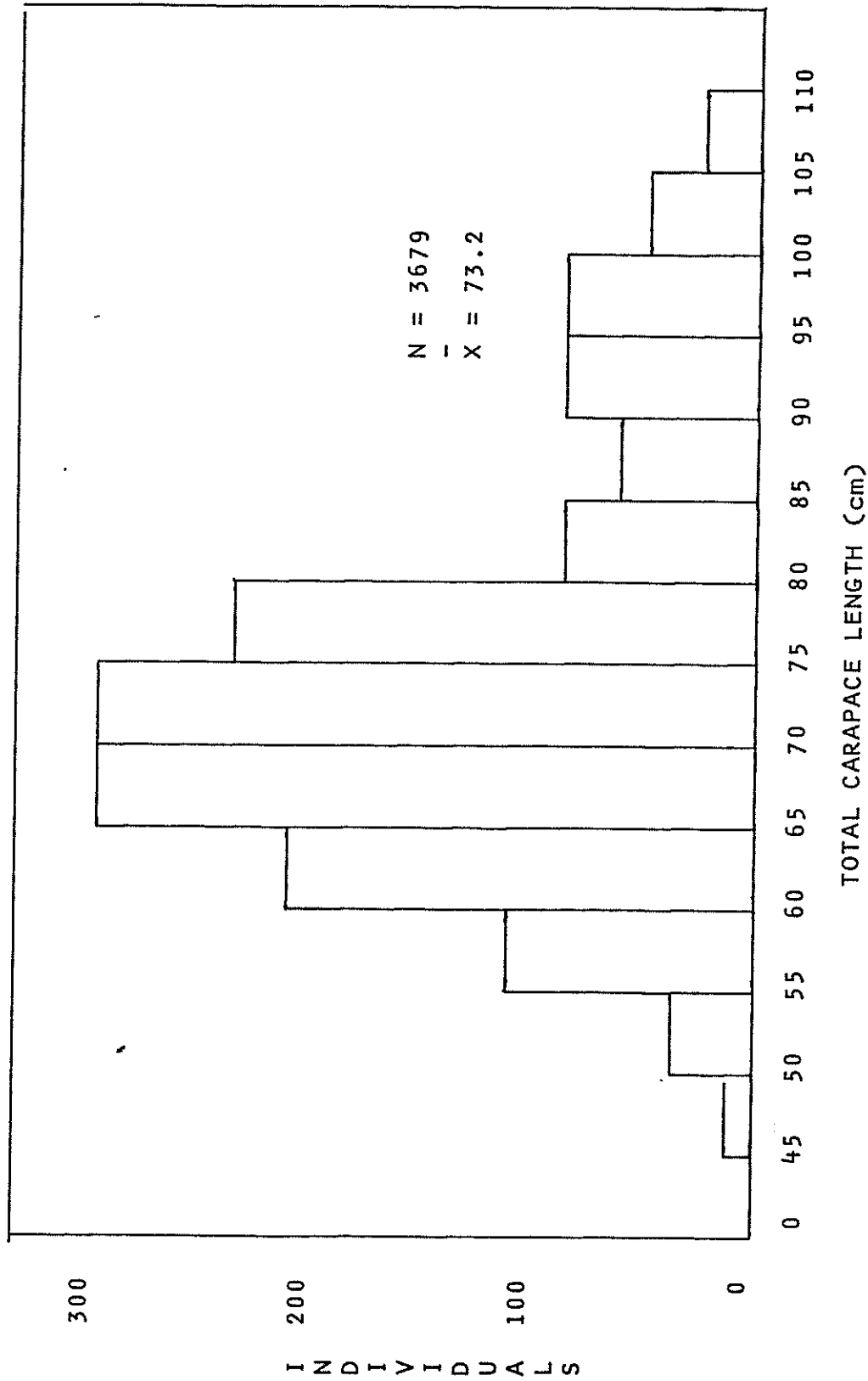


Figure 2. Length frequency distribution of loggerhead turtles, Caretta caretta, captured in the Cape Canaveral area.

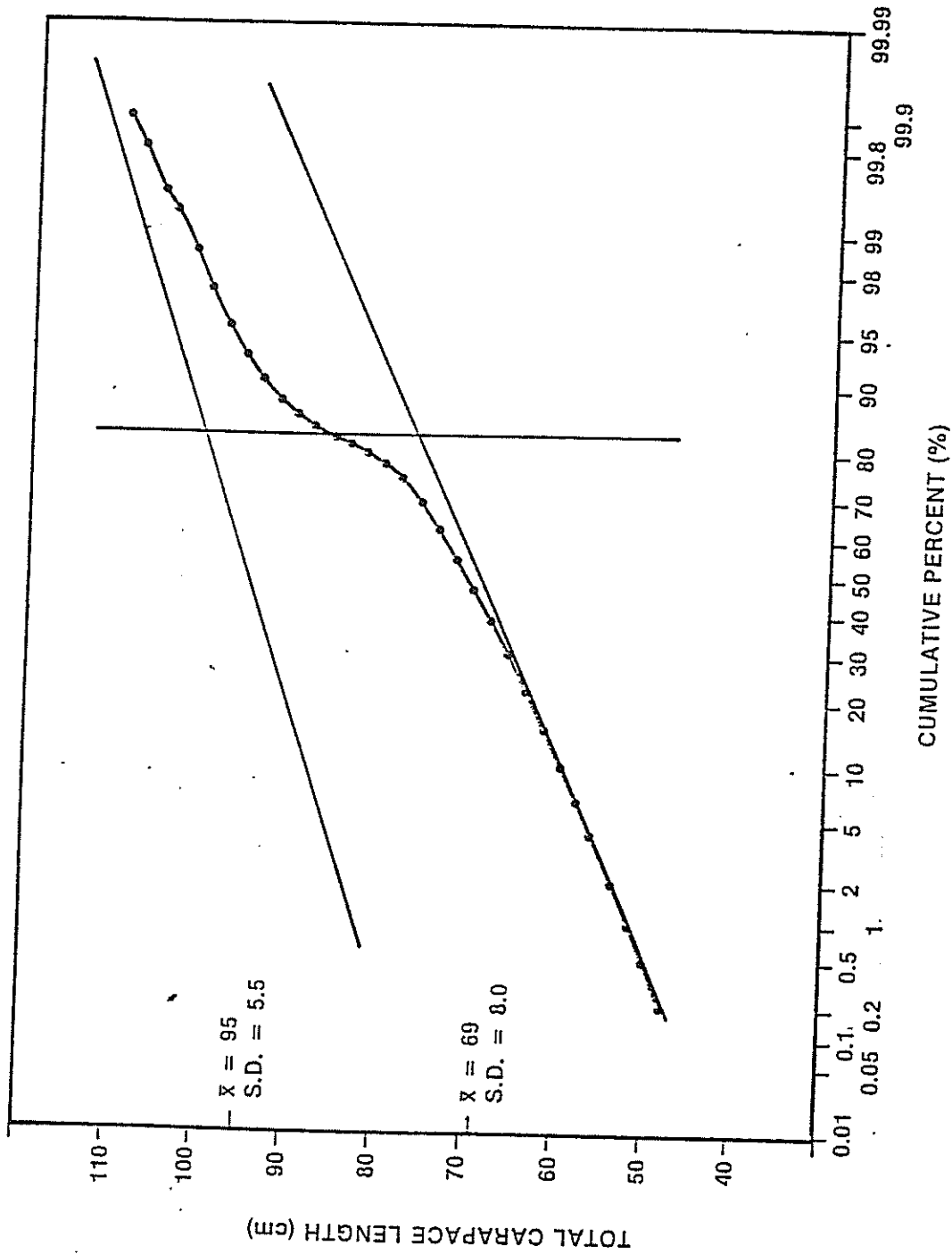


Figure 3. Length frequencies of loggerhead turtles, *Caretta caretta*, captured in the Cape Canaveral area plotted by cumulative percent.

distributions from stranding records in the area (Lew Ehrhart, Univ. of Central Florida, pers. comm.).

The adult size group was separated into male and female components; all remaining turtles (total carapace length 83 cm) were classified as subadults. The Chi-square test of independence of the three sex categories by month was found to be highly significant ($\chi^2 = 1198.2$; $p = 0.001$), indicating that ratios changed over the course of the year. A comparison of predicted vs. observed number of individuals in each category by month (Table 1) indicated that, with the exception of March, all months had significant Chi-square values. The months of April, May and June had highly significant values which accounted for 85 percent of the total. It is during these months that breeding adults are most abundant.

A plot of percent sex composition by month (Fig. 4), illustrates the fact that three groups of loggerhead turtles can be distinguished in the Cape Canaveral study area. Each group is dominant at certain times of the year, and movements of one group into the study area appears correlated with emigration of the remaining two. The numerical abundance of the three groups also changes over the course of the year (Table 1) providing additional evidence of movements into and out of the study area. Separate treatment of the groups was necessary, because

Table 1. Summary of monthly occurrence of loggerhead turtles, *Caretta caretta*, in the Cape Canaveral area by three sex categories (adult male, adult female, and subadult). Predicted number of individuals from χ^2 test of independence (in parentheses) are compared with observed number of individuals.

Month	Subadult	adult male	adult female	total	χ^2
Jan	84 (70.0)	1 (7.9)	1 (8.1)	86	15.05*
Feb	679 (630.3)	50 (70.9)	45 (72.8)	774	20.54*
Mar	442 (435.6)	54 (49.0)	39 (50.3)	535	3.14
Apr	51 (132.7)	100 (14.9)	12 (15.3)	163	537.05**
May	84 (176.7)	56 (19.9)	77 (20.4)	217	271.16**
June	54 (92.0)	4 (10.4)	55 (10.6)	113	205.61**
July	94 (103.4)	5 (11.6)	28 (11.9)	127	27.22*
Aug	265 (255.7)	10 (28.8)	39 (29.5)	314	15.67*
Sept	238 (210.9)	15 (23.7)	6 (24.4)	259	20.55*
Oct	281 (254.9)	15 (28.7)	17 (29.4)	313	14.44*
Nov	598 (530.1)	27 (59.7)	26 (61.2)	651	46.85*
Dec	151 (128.7)	3 (14.5)	4 (14.9)	158	20.96*
Totals	3021	340	349	3710	1198.24**

* $P < .005$

** $P < .001$

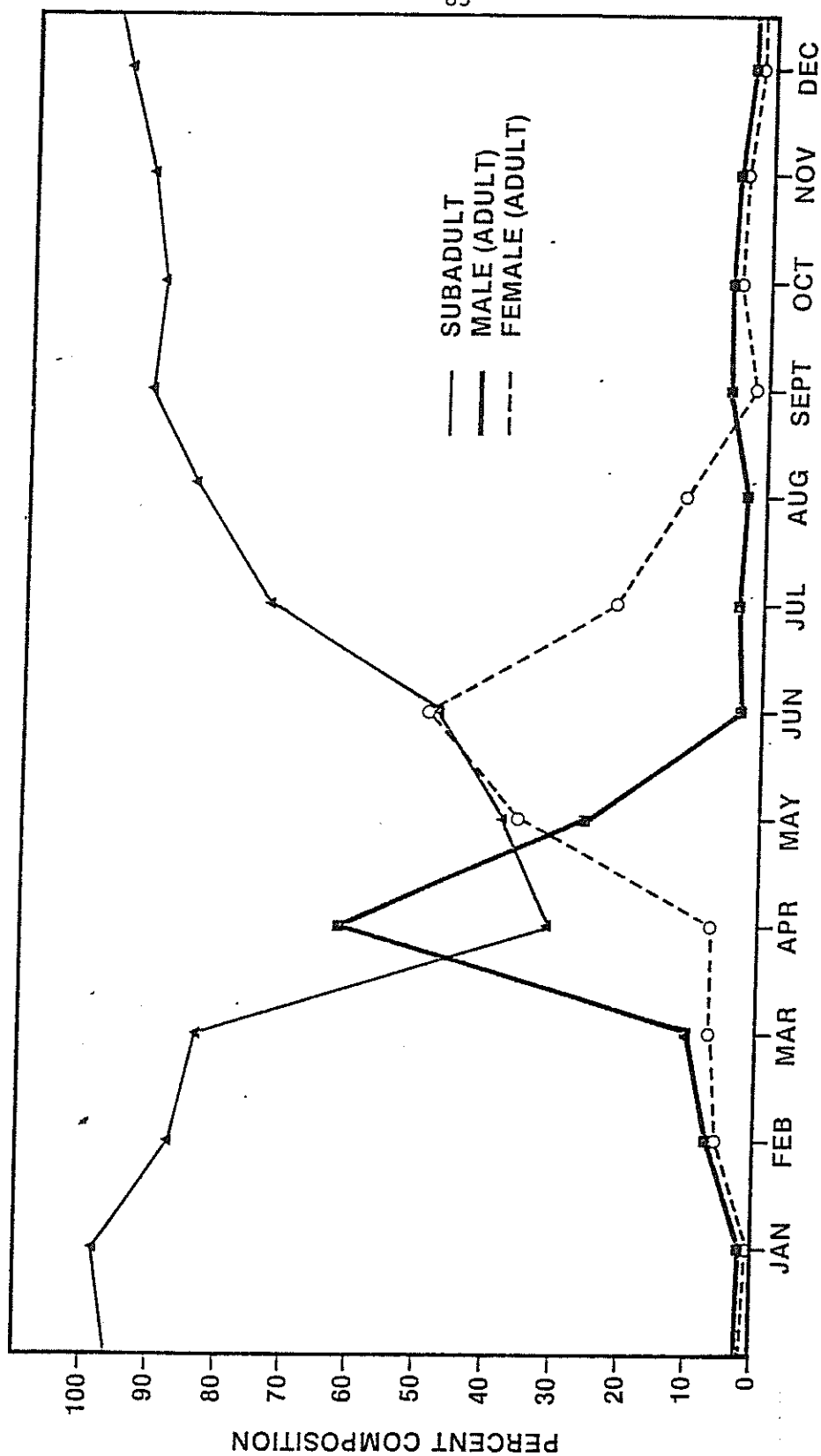


Figure 4. Percent composition of loggerhead turtles, *Caretta caretta*, in three sex categories (adult male, adult female and subadult) captured in the Cape Canaveral area by month. Data were pooled over years.

movements of the three groups were dissimilar and related to different biological and physical factors.

Adult Males

As of December 1984, a total of 340 adult male turtle captures have occurred in the Cape Canaveral area. Seven percent (25 of 340) were recaptures of animals originally tagged in the same location. Twelve of these recaptures occurred within two months of the initial capture. These recoveries provide evidence that some adult males, at least temporarily, reside in the area.

The remaining 13 recaptures after periods ranging from 7 to 26 months, and all occurred between February and June. In seven instances, turtles initially captured between February and May were recaptured during the same time period one or two years after tagging. These turtles are presumed to be members of the breeding population. To my knowledge, no adult male turtles tagged in this study have been recaptured outside of the Canaveral area.

Adult Females

A total of 349 adult female turtle captures were recorded in or near the Cape Canaveral ship channel. The months of May through August produced fifty-seven percent

(199 of 349) of the captures, and these months correspond with peak nesting activity on area beaches (Ehrhart, 1979). Thirty-four percent (67 of 199) of the females were observed nesting on local beaches either before or after capture.

During the remainder of the year (September through April) 150 adult females were captured; seven percent (11 of 150) of these had been observed nesting in preceding years. Six of these eleven recaptures occurred in March and April 1980, and may have been early arrivals for the nesting season. Three of the remaining five were from Georgia nesting populations (Jim Richardson, Univ. of Georgia, pers. comm.) and one was from the Jupiter Island, FL nesting population. Only one adult female captured during the winter months was known to have nested on local beaches of the Canaveral area.

Movements of four adult female turtles were over distances greater than 100 nautical miles. One animal tagged in the Canaveral area during February 1982 nested on Blackbeard Island, GA the following summer. A second female was washed ashore dead on Cumberland Island, GA during the summer after capture in the Canaveral ship channel. A third female tagged in the Canaveral channel nested on Melbourne Beach, FL and was subsequently recaptured near Key West, FL. A fourth female nested on Cumberland Island, GA in 1975 and was recaptured in the Canaveral channel in February 1978 and again in October 1980.

Subadults

Of 3021 subadult captures in the Canaveral area, ninety-one percent (2738 of 3021) occurred during the months of August through March. Sixteen percent of the total (475 of 3021) were recaptures of turtles originally tagged in the same location. Periods between capture ranged from 0 to 1479 days, and one turtle was captured on six separate occasions.

Twenty-nine subadult turtles were recaptured more than 100 nautical miles from the study area. Twenty-seven of these were to the north along Georgia, South Carolina, and Virginia; the remaining two were taken in the Bahama Islands (Fig. 5).

The majority of initial captures of subadults in the Canaveral area (27 of 29) occurred from October to March, while the majority of recaptures (22 of 29) were from May to September. This pattern suggests a northward movement during spring and summer associated with warming waters in higher latitudes.

During the 1980 relocation project, 1161 subadult turtle captures were recorded. Over the five-month period of the project, catch per unit effort (CPUE) of subadult loggerheads increased significantly (Table 2). Examination of CPUE (standardized to 30.5 m net hours) by month

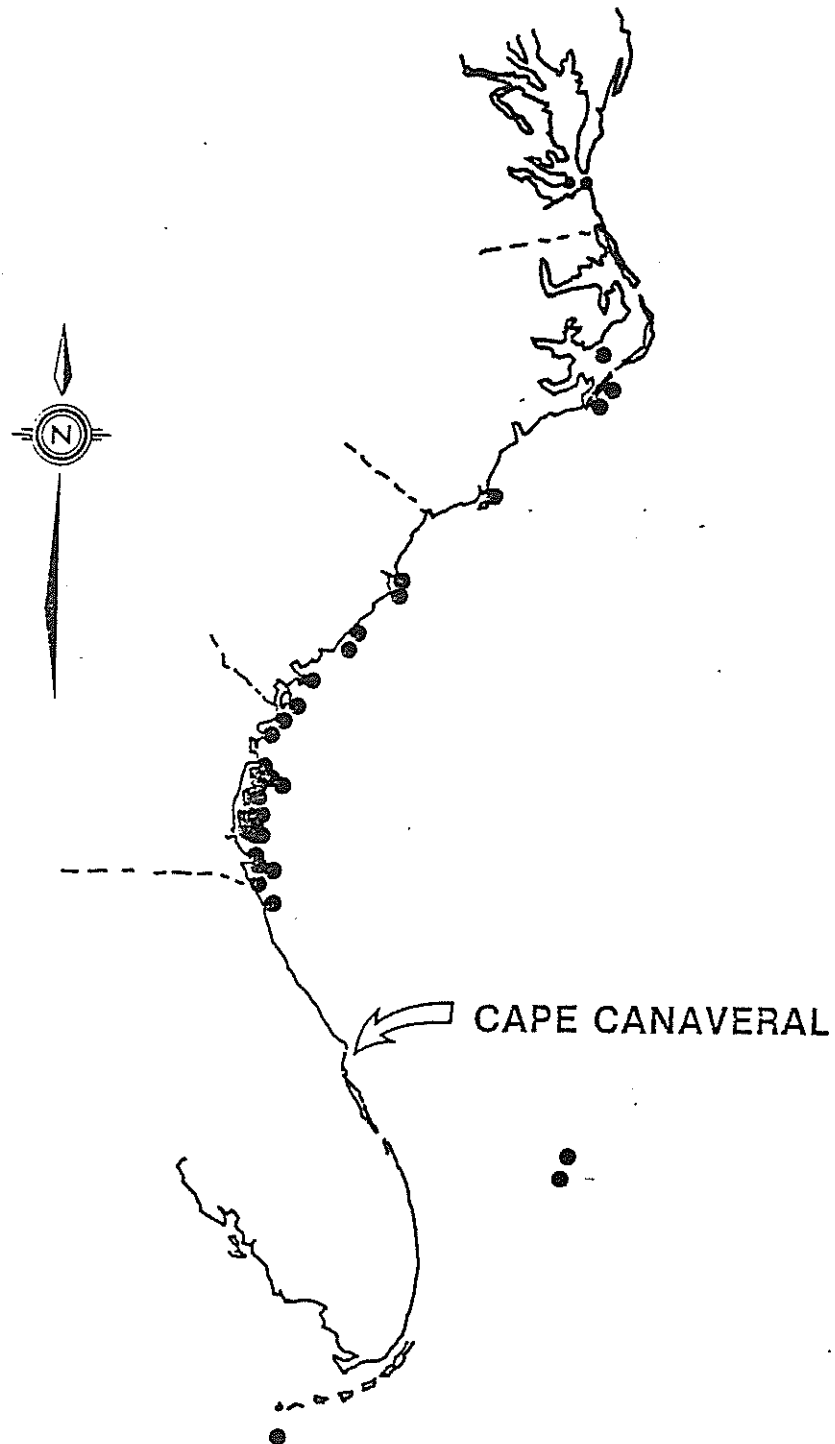


Figure 5. Summary of long-distance recaptures from loggerhead turtles, *Caretta caretta*, originally captured and tagged in the Cape Canaveral area.

Table 2. Summary of subadult loggerhead turtle, Caretta caretta, captures, recaptures and CPUE in the Cape Canaveral ship channel (July to November, 1980).

Month	Minutes Fished	Effort (30.5m net hrs)	Turtle Captures	CPUE (turtles/hr)	Recaptures	Percent Recaptures
July	1834	24.45	49	2.00	8	16
Aug	3916	52.21	175	3.35	24	14
Sept	4657	62.09	178	2.87	40	22
Oct	4075	54.33	264	4.86	73	28
Nov	3082	41.09	495	12.05	149	30

indicated that the catch rates were low but stable from July to September (2.00 to 3.35 turtles/hr). In October the CPUE approximately doubled (4.86 turtles/hr) and doubled again in November (12.05 turtles/hr). This suggests that the number of subadult turtles in the channel by November was four times larger than in summer.

The percentage of tagged animals recaptured also increased steadily in fall, reaching thirty percent by November. Seventy-nine percent of these recaptures (233 of 294) were turtles tagged during the relocation project. This indicates that the animals remained in the channel and were not migrating through the area. The other twenty-one percent (61 of 294) were animals tagged during prior winter surveys. These recaptures suggest that many individuals overwinter in the channel each year. Of this latter group, 46 were initially tagged in winter 1979-80, 12 in winter 1978-79, and 3 in winter 1977-78.

SUMMARY AND DISCUSSION

Because size and sex composition of sea turtle aggregations in the Canaveral area changed seasonally, three groups (adult males, adult females and subadults) were treated independently. Migrations of adult turtles into the area during spring and summer months probably were related

to reproductive behaviors and do not reflect normal foraging patterns or non-breeding distributional patterns. Subadult turtle movements, however, probably were not related to sexual activities; their distribution patterns may reflect changes in environmental conditions and foraging opportunities.

The bimodal size distribution of turtles in the study area reflects the seasonal influx of breeding adults. During the remainder of the year adult turtles are less common, which indicates that many of these turtles leave the area. The size distribution of turtle aggregations during non-breeding periods is unimodal with larger subadults and adults occurring in low numbers. Movements of older turtles out of the Canaveral channel may be associated with the onset of sexual maturity in one or both sexes, or may reflect differential habitat preferences in larger turtles.

With regard to turtles initially tagged in the Cape Canaveral area and recaptured in the same locality, little can be said about where they moved during periods between capture. These data are useful, however, as an indicator of emigration and immigration over the course of a year. Changes in percent composition of the sexes and CPUE indicate that turtle aggregations are dynamic and that turtles move into and out of the area regularly.

Adult Males

Adult male migratory patterns appear different from those of adult females, with males moving into the Canaveral area prior to the arrival of females. Peak densities were April to May. Breeding presumably occurs at this time, and most males leave the area by June. The same male turtles are sometimes present in Cape Canaveral breeding aggregations during consecutive years and are intermittent members of the overwintering assemblage of turtles. This indicates that adult males may remain in the proximity of breeding areas throughout the year. The presence of the same males during consecutive years just prior to the time when females nest, suggests that males breed annually and do not migrate with the females. If males breed each year, the sex composition of adult populations could be different from the expected 1:1 ratio, since a single group of males could breed with different females each year.

Adult Females

Results of this study suggest that females nesting in the Canaveral area rarely overwinter in the channel, and adult females encountered during the winter are either non-breeding adults or members of other nesting populations. The breeding population of female turtles, dominant from May

to August, consists of short-term residents which migrate into the area for nesting. At the end of the nesting season, these turtles apparently emigrate to distant foraging and feeding areas and do not return until the next nesting cycle.

Subadults

Subadult turtles are dominant in the Canaveral Ship Channel from August to March. In the spring, subadults emigrate in some instances as far north as the Chesapeake Bay. The majority of the long-distance recoveries occurred north of Cape Canaveral, but these recoveries may represent a biased impression of dispersal patterns because most came from shrimp trawlers or beach washups. Fishing pressure from shrimp trawlers is much greater north of Canaveral and the increased level of fishing effort in these areas could account for the large number of northern records. Without comparable effort to the south, it is difficult to determine whether more animals move northward, southward or in equal numbers in both directions.

Results of the joint COE-NMFS study and other NMFS surveys in the Cape Canaveral area indicate that subadult turtles begin to congregate in the fall, presumably in response to cooling water temperatures and winter conditions. Greatest concentrations occur from October to

March, and many of the same turtles may be present each year. Turtles apparently remain throughout the winter, leaving the channel in the spring as improved environmental conditions and foraging opportunities occur. These data indicate the existence of a resident population of subadult turtles in the Cape Canaveral ship channel during winter months, which disperses locally during spring and summer and returns to the channel each winter.

ACKNOWLEDGEMENTS

I thank all persons who participated in the collection of data used in this manuscript. In particular, I wish to acknowledge the contributions of Frederick Berry, Andy Kemmerer, Wilber Seidel, Steve Malvestuto, Ann Williams, Niki Bane, Warren Stuntz and Ren Lohoefer.

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VII. SEASONALITY AND ABUNDANCE OF LOGGERHEAD SEA TURTLES
(CARETTA CARETTA) IN FIVE EASTERN FLORIDA CHANNELS
AND INLETS

By

Richard W. Butler, Walter A. Nelson and
Tyrrell A. Henwood

ABSTRACT

Five eastern Florida navigational channels were surveyed on a quarterly basis from November, 1981 through August, 1982. The purpose of the surveys was to provide estimates of sea turtle abundance for each channel over all seasons of the year. Standard methods for estimating turtle abundance from trawl samples were developed, and the probability of capture in a 30-m by 1,483-m substation (p) was estimated to be 0.28 ± 0.05 (95% confidence level). Abundance estimates based on this probability of capture were then developed for each channel and survey. Results indicated that of the channels surveyed, only Cape Canaveral harbored significant concentrations of turtles; populations

ranged from 701 ± 291 turtles in February to a low of 38 ± 26 turtles in August. A few turtles were captured in the other channels, but infrequency of occurrence suggested random encounters rather than areas of concentration.

INTRODUCTION

In the western Atlantic Ocean, loggerhead turtles, Caretta caretta forage throughout the warm waters of the continental shelf from Argentina northward to Nova Scotia, including the Gulf of Mexico and the Caribbean Sea (Carr, 1952). On a seasonal basis, loggerheads are common as far north as the Canadian portions of the Gulf of Maine (Lazell, 1980), but during cooler months of the year distributions shift to the south (Shoop et al., 1981). Sporadic nesting occurs throughout the tropical and warm temperate range of distribution, but the most important nesting areas are along the Atlantic coast of Florida, Georgia and South Carolina (Carr and Carr, 1978). The Florida nesting population of Caretta has been estimated to be the second largest in the world (Ross, 1982).

Although population levels of adult female loggerheads can be estimated from counts on nesting beaches, the remaining animals (males, subadults and non-breeding females) do not come ashore and are not readily available for census. To estimate the number of turtles in an area,

all segments of the population should be considered in addition to the nesting females.

In the vicinity of Cape Canaveral, FL loggerhead turtles congregate in the Cape Canaveral ship channel (Carr et al., 1980). This unique situation has prompted surveys by the National Marine Fisheries Service (NMFS) to monitor population levels and estimate relative turtle abundance. This study is a continuation and expansion of research efforts which began in 1978.

Presented are results of a 1-year investigation conducted in response to requests from the U.S. Army Corps of Engineers (COE) and the U.S. Navy, to estimate sea turtle abundance and seasonality in five eastern Florida navigational channels. Animals captured in this study were subadults, adult males and adult females. Population estimates of subadult turtles may prove to be particularly useful for management, as efficacy of conservation measures should be first evident in the population levels of the youngest cohorts.

Results of this study provide a reliable index of sea turtle abundance for the study year, and an alternative to population estimates based only on nesting females. Most importantly, for the first time, a standard method has been developed that provides sea turtle abundance estimates with approximate standard errors.

STUDY AREAS

Five eastern Florida navigational channels were surveyed on a seasonal basis over the study period. A description of the survey sites follows; each site is diagramed in Fig. 1.

(1) St. Mary's entrance to King's Bay ($30^{\circ} 43'N$; $80^{\circ} 20'W$) is divided by the state boundary between Georgia and Florida and includes Cumberland Sound through which the Intracoastal Waterway connects King's Bay with the entrance channel. Mud predominates inside of the jetties, and mud and rock bottom are found in the channel offshore.

(2) Ponce de Leon Inlet ($29^{\circ} 04'N$; $80^{\circ} 53'W$), on the northeast coast of Florida, is a small inlet accessible only to small craft. A jetty protects the inlet to the north; inside the inlet a narrow channel leads to the Intracoastal Waterway. The substrate is hard sand and silt with scattered rubble.

(3) The Cape Canaveral ship channel is located on the central east coast of Florida ($28^{\circ} 23'N$; $80^{\circ} 33'W$). The ship channel allows navigation from offshore, through a man-made inlet, into a protected harbor. A depth of 11 to 13-m is maintained by dredging. Soft mud and detritus bottom

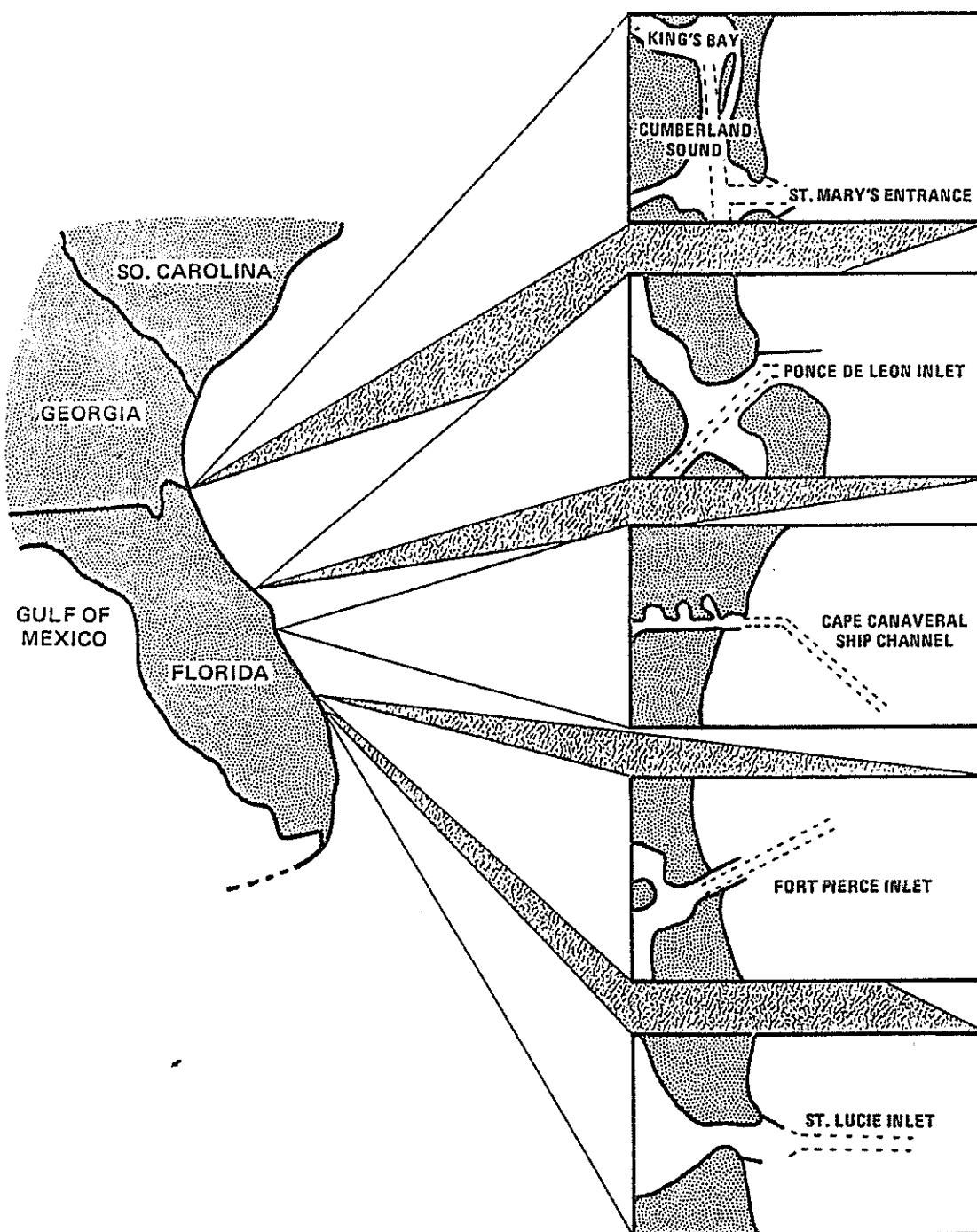


Figure 1. Description of five eastern Florida navigational channels and inlets surveyed in this study.

is found in the channel and sand-clay in the surrounding areas.

(4) Fort Pierce Inlet ($27^{\circ} 28'N$; $80^{\circ} 16'W$) is located on the south-central east coast of Florida. The channel allows navigation from offshore, through the inlet that is protected by jetties, into the Intracoastal Waterway. The bottom is hard sand and rubble.

(5) St. Lucie Inlet, also on the south-central east coast of Florida ($27^{\circ} 09'N$; $80^{\circ} 07'W$), is another small inlet with use limited to small craft. A completed jetty protects the north side of the inlet and a second jetty was under construction to the south during the survey periods. The substrate offshore is sloping hard sand and silt.

MATERIALS AND METHODS

Quarterly trawl surveys of the navigational channels were conducted from November, 1981 through August, 1982. During quarterly trawl surveys, the Cape Canaveral ship channel was sampled twice and the remaining four sites (St. Mary's entrance, Ponce de Leon Inlet, Fort Pierce Inlet and St. Lucie Inlet) were sampled once. A standard 18-m "mongoose" fish trawl, spread by 3-m X 1-m trawl doors and

equipped with mudrollers, was used throughout the study period.

Prior to the surveys, the boundaries of each channel were located using National Ocean Surveys charts and subdivided by a grid pattern for systematic sampling. Lengthwise, each channel was separated into 1,483-m stations which were divided into 30-m wide substations (Fig. 2). The number of substations in each station was dependent on channel width.

A systematic sampling scheme was devised to sample each channel substation: every other station was sampled in leap-frog fashion in one direction, and then the direction was reversed. The substation sampled within each station was determined by random drawing without replacement, and sampling continued until all substations were occupied. This approach avoided the "edge effect", but allowed samples to be statistically treated as random (Milne, 1959). Control samples outside the channel were taken at all sites during each survey period.

In addition to standard survey procedures, experiments designed to estimate gear efficiency were conducted in the Cape Canaveral ship channel. Following each survey, a substation with abundant sea turtles was selected, and a series of repetitive tows performed. Tows were continued in rapid order until two consecutive samples yielded zero catches or the working day ended.

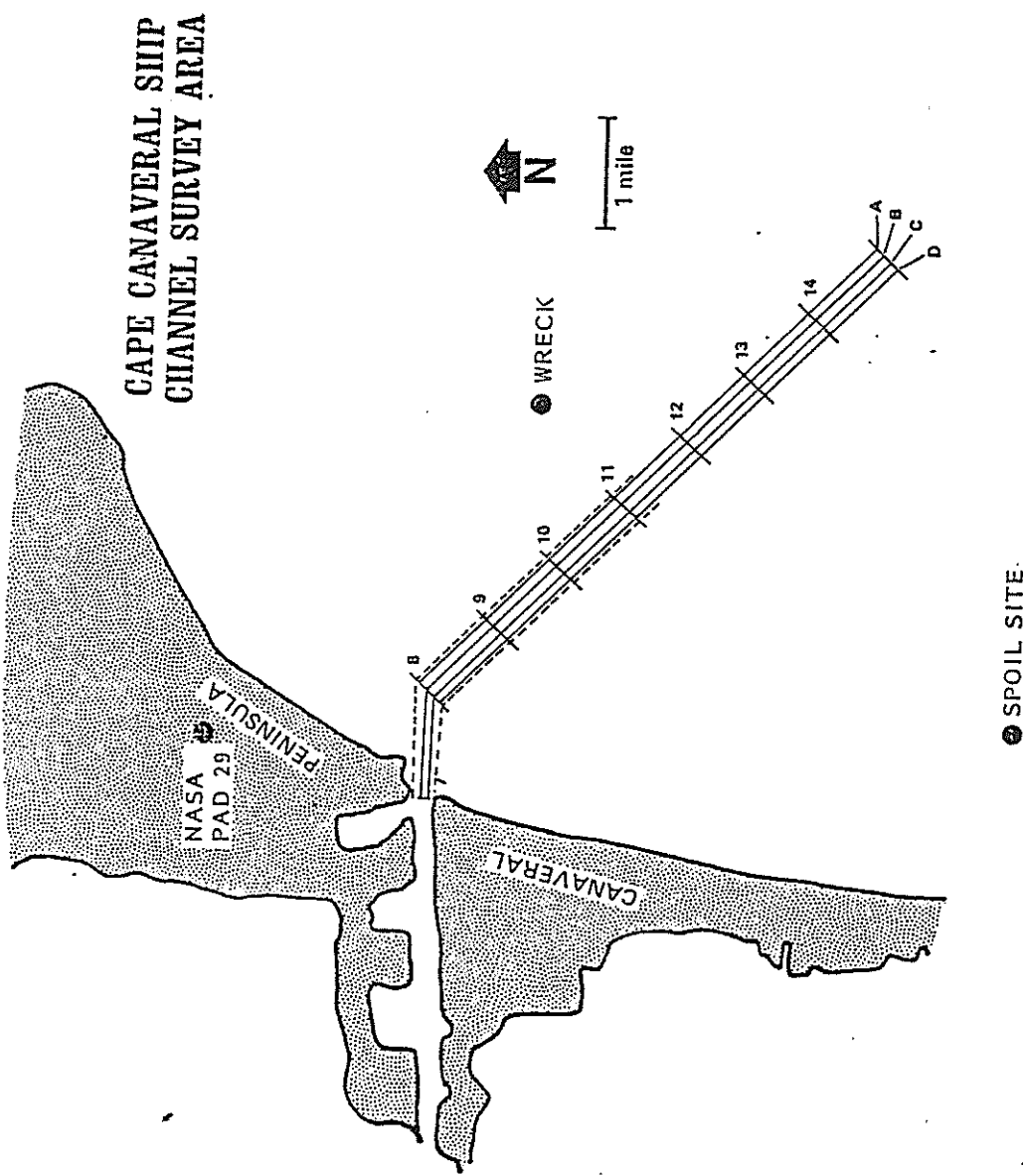


Figure 2. Description of the Cape Canaveral ship channel survey area. The channel was separated into 1,483-m stations (7-14) which were divided into 30-m wide substations (A,B,C and D).

ANALYTICAL PROCEDURES

Before population estimates were computed, it was necessary to establish the efficiency of the sampling gear. The probability of turtle capture (\hat{p}) was estimated for each repetitive towing experiment using the formula:

$$\hat{p} = C_1 / \hat{N}_0$$

where

C_1 = catch on the first tow in the substation

\hat{N}_0 = estimated number of turtles in the substation.

A regression of cumulative turtle catch (Y) on catch per sample (X) expressed as $Y = b_0 + b_1X$ was used to estimate (\hat{N}_0) based on the relationship: $\hat{N}_0 = b_0$. The estimated variance of \hat{N}_0 was calculated according to procedures of Kleinbaum et al. (1978):

$$\text{Var} (\hat{N}_0) = (\text{Se})^2 \left[1/n + \bar{X}^2 / \sum (X_i - \bar{X})^2 \right]$$

where

Se = standard error of the estimate provided by the straight line fit

n = sample size of the catch data set

X_i = observed catch per sample in the i^{th} sample and

$$\sum (X_i - \bar{X})^2 = \sum X_i^2 - \sum (X_i)^2 / n.$$

The estimated variance of \hat{p} was then calculated using procedures of Mood et al. (1974):

$$\text{Var}(\hat{p}) = (C_1/\hat{N}_0^2)^2 \text{Var} \hat{N}_0.$$

In one instance, the experiment was conducted in an area larger than the standard substation and a ratio (standard area/larger area = 0.75) was used as a constant multiplier to standardize estimates.

The mean probability of capture was calculated by combining all experimental \hat{p} 's using the formulae:

$$\hat{p} = \sum \hat{p}_i / k, \text{ and } \text{Var}(\hat{p}) = \sum \text{Var}(\hat{p}_i) / k^2$$

where

k = number of estimates.

Once the efficiency of trawling equipment had been determined, the number of turtles present in a substation (\hat{N}) was estimated using the following formula (Seber, 1973):

$$\hat{N} = C/p$$

where

p = probability of capture

C = number of animals captured.

If more than one sample tow was made in a substation, the mean catch (\bar{C}) was substituted in the above formula. To estimate the number of turtles in a channel substation, station, or the entire channel, the mean number captured per substation sample (\bar{C}) times the number of substations (s) was substituted: $\hat{N} = s\bar{C} / \hat{p}$. The estimated variance of this estimate is (Mood et al., 1974):

$$\text{Var}(\hat{N}) = (s/\bar{p})^2 [\text{Var}(\bar{C}) + (\bar{C}/\hat{p})^2 \text{Var}(\hat{p})].$$

RESULTS

Estimates of the probability of capture and associated standard error estimates from nine repetitive trawl experiments are presented in Table 1. Estimated probability of capture within a substation based on six experiments ranged from 0.21 to 0.31 ($\hat{p} = 0.28$; 95% confidence interval = ± 0.05 ; estimated variance = 5.18×10^{-4}). Three experiments were excluded from the analyses: two were discarded because the catch failed to decline due to low population levels, and a third was eliminated because of problems with the sampling trawl.

Estimates of turtle abundance by survey for the Cape Canaveral ship channel ranged from 701 ± 291 turtles in late February, 1982 to a low value of 38 ± 26 turtles in late August, 1982 (Table 2). Cape Canaveral channel stations 9

Table 1. Estimated probability of turtle capture in a Cape Canaveral ship channel substation using an 18-m fish trawl.

DATE	CATCH ON FIRST TOW (C_1)	POPULATION ESTIMATE (N_0)	PROBABILITY OF CAPTURE (\hat{p})	SE (\hat{p})	APPROXIMATE 95% c.i. (\hat{p})
11/ 6/81	8	20.19	0.40	0.09	± 0.17
12/ 5/81	6	19.54	0.31	0.01	± 0.02
12/ 7/81	13	51.48	0.28	0.03	± 0.07
2/28/82	7	30.31	0.23	0.02	± 0.04
3/ 2/82	15	72.85	0.21	0.07	± 0.13
5/23/82	2	data set discarded			
5/28/82	2	data set discarded			
6/ 1/82	1	data set discarded			
6/ 6/82	3	11.82	0.25	0.05	± 0.10
mean (\hat{p})			0.28	0.03	± 0.05

Table 2. Estimated number of turtles (\hat{N}) at Cape Canaveral ship channel by station and survey period (1981-1982).

Station	Nov. 3-5	Dec. 2-4	Feb. 3-6	Feb 21-26	May 7-12	May 28-June 1	Aug. 4-5	Aug. 20-22
7	*	*	0**	0**	21**	0**	14**	0**
8	*	*	25	43	29	11	21	0
9	93	32	114	143	29**	21	57	7
10	64	32	254	221	32	21	61	18
11	21	7	157+	146	21	36	8	7
12	21	4	43	89	7	21	4	4
13	0	0	0	11	10**	0	0	0
14	0	0	0	4	0**	0**	0	0
Channel	200++	75++	632	701	152	122	168	38
Approx. 95% c.i.	± 129	± 50	± 314	± 291	± 86	± 62	± 82	± 26

* Station not sampled.

** Station incompletely sampled.

+ Includes 4 Kemp's ridley turtles, Lepidochelys kempi.

++ Estimate is for stations 9-14, others are for 7-14.

through 11 (Fig. 2) exhibited the highest turtle abundance during all seasons of the year. Mean catch for all samples in the channel was 2.55 turtles/tow and 0.50 turtles/tow for control samples, supporting the hypothesis that turtles congregate in the Cape Canaveral ship channel.

Turtle abundance estimates for the remaining four survey sites were low during all seasons of the year (Table 3). Over the study period, a total of 18 loggerhead turtles was captured: two at St. Mary's entrance, six at Ponce de Leon Inlet, three at Fort Pierce Inlet and seven at St. Lucie Inlet.

DISCUSSION

Our estimates of the probability of capture were based on the supposition that catch-per-tow in a given substation will decrease as turtles are removed. The regression of cumulative turtle catch on catch per sample can then be used to estimate the original population size in the substation (Brownlee, 1965) and using this estimate, the probability of capture can be computed. Assumptions associated with this procedure are a closed population, the trawl fishes only within the defined bounds of the substation, each tow is an equal unit of effort and the probability of capture remains constant.

Table 3. Estimated loggerhead turtle abundance during quarterly surveys of St. Mary's entrance - King's Bay, Ponce de Leon Inlet, Ft. Pierce Inlet and St. Lucie Inlet.

Date	St. Mary's King's Bay	Ponce de Leon Inlet	Fort Pierce Inlet	St. Lucie Inlet
11/81	9 \pm 18	0	0	0
2/82	0	11 \pm 15	4 \pm 7	4 \pm 7
5/82	0	0	4 \pm 8	11 \pm 11
8/82	0	0	0	4 \pm 7

Although these assumptions may not be satisfied in all cases, our estimates of probability of capture in a given substation were consistent except for the two discarded experiments conducted during periods of low turtle densities. These findings suggest that some turtles encountering the trawl were able to avoid capture, presumably by moving out of the trawl path. The results also indicate that a consistent percentage of turtles were captured by the trawl, facilitating the estimation of turtle abundance based on number of turtles captured. It should be noted, that the probability of capture in a given substation (as presented in our results) is lower than the probability of capture in a given tow. To compute the probability of capture in a single tow, the width of the substation is divided by the width of the trawl and this factor multiplied by the probability of capture in the substation.

Sea turtle abundance estimates in the Cape Canaveral ship channel exhibited large seasonal variation (Fig. 3). The estimated population levels during the month of February were significantly higher than all other quarterly surveys indicating that turtles were most abundant during winter months. These findings are in agreement with other NMFS surveys in the Canaveral channel from 1978-1983 (Table 4), and support the contention of Carr et al. (1980) that turtles may hibernate in the Cape Canaveral channel in refuge from low water temperatures. The fact that the

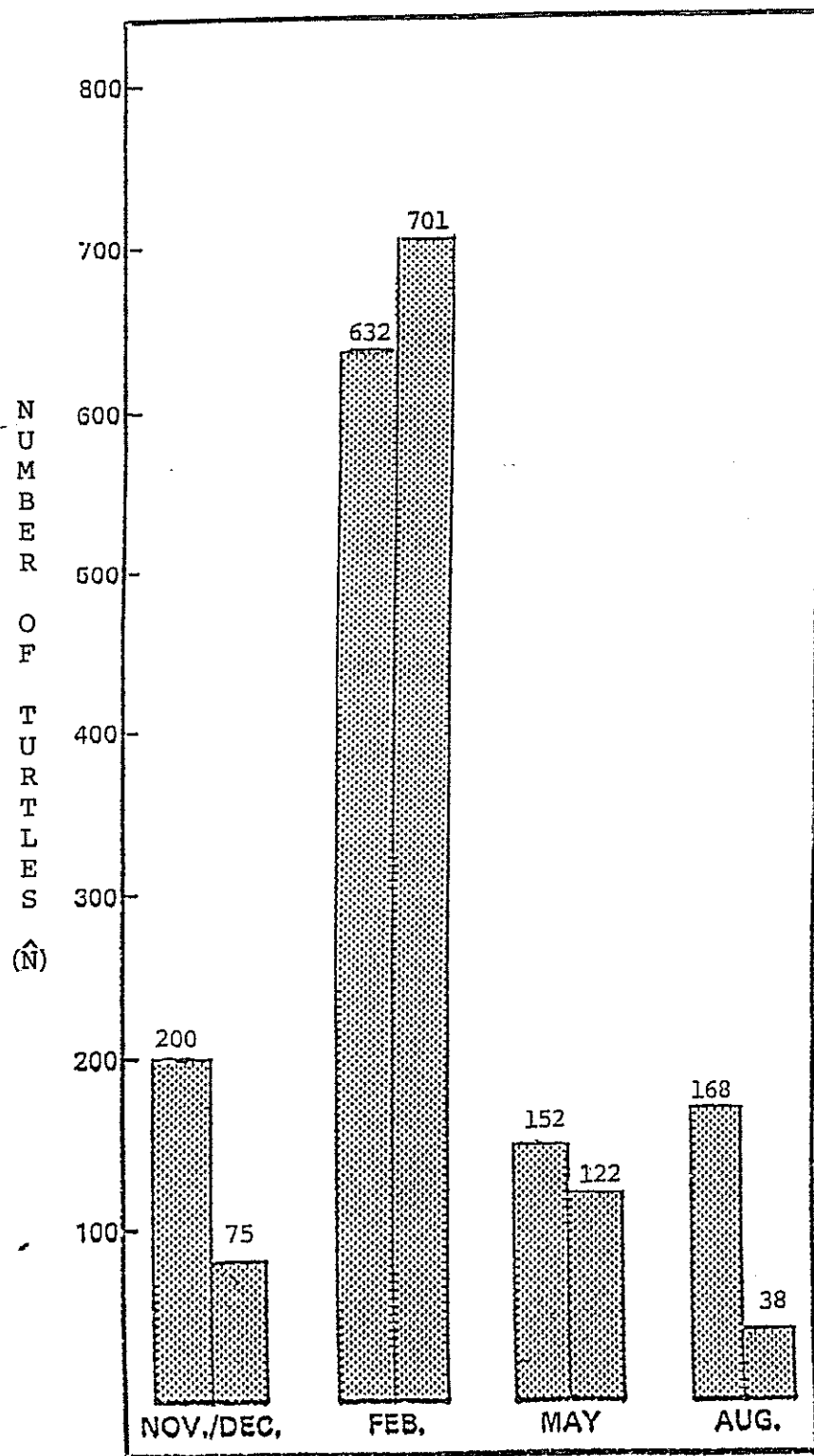


Figure 3. Loggerhead turtle abundance estimates (\hat{N}) from quarterly surveys of the Cape Canaveral ship channel.

Table 4. Summary of catch per unit effort (CPUE) of loggerhead turtles, Caretta caretta, in the Cape Canaveral ship channel (1978-1983). Values are in turtles/hr. standardized to a single 100 ft net, N = number of tows.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1978		37.74 N = 7	55.73 N = 7							18.99 N = 5	10.82 N = 10	21.64 N = 14
1979	11.56 N = 17	11.88 N = 11	8.21 N = 11	9.13 N = 3	1.33 N = 5	21.25 N = 16	13.86 N = 32		9.43 N = 28			
1980	24.82 N = 19	19.61 N = 40	28.57 N = 77		3.38 N = 22	3.77 N = 22	3.31 N = 60	3.29 N = 152	2.62 N = 189	5.44 N = 135	11.81 N = 105	5.11 N = 7
1981	15.89 N = 12			11.22 N = 16				7.88 N = 41	3.26 N = 51		22.06 N = 29	7.18 N = 42
1982	41.83 N = 99	58.53 N = 14			7.49 N = 96	4.24 N = 15		5.95 N = 83				
1983			4.86 N = 20	2.35 N = 60								
Totals	18.56 N = 36	32.61 N = 169	27.88 N = 129	4.21 N = 79	6.50 N = 123	9.18 N = 53	6.98 N = 92	4.77 N = 276	3.45 N = 268	5.92 N = 140	13.80 N = 144	10.16 N = 63

winter of 1981-1982 was unusually mild, could account for the lack of an early winter peak in turtle abundance observed in previous years.

Data presented in Table 4, while of limited statistical value due to inconsistencies in sampling methodologies, are useful for comparisons between this study and other NMFS Canaveral channel surveys. It is worthy of note that mean catch per unit effort (CPUE) by month combining all years was in excess of 10 turtles/hr from November through March with peak concentrations in February and March. Lowest CPUE values and presumably population levels occurred from April through September which is in agreement with our findings.

It is evident that sea turtle abundance estimates were highly variable between surveys made in the same quarter (Table 2). We speculate that these fluctuations in population levels were caused by short-term immigration and emigration related to local weather changes. We have observed daily changes in catch rates which appear to be correlated with passage of weather fronts.

Distribution of sea turtles within the channel is also of interest. In every survey, stations 9, 10 and 11 exhibited the highest abundances suggesting that they were preferred turtle habitat. Stations 7, 8 and 12 exhibited intermediate population levels and stations 13 and 14 had low turtle abundance levels. Stations 7, 8, 9 and 10 were those where deepest cuts into the sea bed have been made by

dredging. The bottom was characterized by divers as clay-silt and detritus as opposed to the harder clay-sand bottom outside the channel (Carr et al., 1980).

Interpretation of turtle abundance estimates generated from this study is complicated by the fact that three different groups of loggerheads (adult males, adult females and subadults) utilize the channel at different times of the year (Henwood, in press). Adult males are dominant in April and May, adult females are most abundant from May through August and subadult turtles are predominant during the remainder of the year. For this reason, direct comparisons between quarterly surveys may be inappropriate.

It is unfortunate that the three discarded repetitive trawl experiments occurred in May and June when the population was comprised primarily of breeding adults. Low population levels at this time may reflect a reduced catchability coefficient in adult turtles possibly associated with behavioral changes. The ability of turtles to escape trawls may also be enhanced during periods of warm water temperatures, but no evidence of this was noted during August or November.

Turtle abundance in the remaining four channels was low during all quarterly surveys. These findings confirm the presence of loggerhead turtles along much of Florida's eastern coastline, but do not indicate any channel areas with turtle concentrations similar to Cape Canaveral. It is

of special interest that only Cape Canaveral, a man-made habitat, harbors concentrations of turtles throughout the year and particularly during winter months.

The St. Mary's entrance to King's Bay survey area was by far the largest site investigated, and may have been incompletely sampled relative to the total area involved. This location was of particular interest to the U.S. Navy because of planned construction of a Trident submarine base in King's Bay. Although no concentrations of turtles were noted over the course of this investigation, future dredging of this channel could potentially result in a situation similar to Cape Canaveral, with turtles congregating in a deepwater man-made habitat.

ACKNOWLEDGEMENTS

Funding for this investigation was provided by the U.S. Army Corps of Engineers, the U.S. Navy and the National Marine Fisheries Service. The statistical approach was based on recommendations of Dr. Al Rainosek.

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VIII. LOSSES OF MONEL FLIPPER TAGS FROM LOGGERHEAD
SEA TURTLES, CARETTA CARETTA

By

Tyrrell A. Henwood

Sea turtle researchers throughout the world have no reliable cost effective method to permanently mark or tag turtles. In recent years, most sea turtle tagging programs have used either Monel flipper tags (National Band and Tag Company, Newport, Kentucky) or plastic jumbo Rototags (Dalton, Henley, England)(Hughes, 1981), though neither has been very effective as a permanent attachment (Hughes, 1974b; Schulz, 1975; Richardson et al., 1978; Green, 1979; Carr, 1980; Cornelius and Robinson, 1982). The tag loss problem has received considerable attention, but debate continues on which tag is best and what can be done to improve retention rates (Marine Turtle Newsletter Nos. 1, 2, 3, 5, 13, 19, 20, 22).

The National Marine Fisheries Service (NMFS) has conducted sea turtle research in southeastern United States

coastal waters since 1978. NMFS projects have utilized trawling gear in the capture of turtles, and all turtles have been tagged with Monel alloy flipper tags. On the basis of recaptures of tagged individuals, we estimate the probabilities of losing a Monel flipper tag applied to loggerhead turtles, Caretta caretta. Known probabilities of tag loss over time are essential in developing meaningful population estimates because failure to consider tag losses will lead to an overestimation of true population abundance.

Three different Monel flipper tags were utilized in NMFS tagging projects. Large tags (NBTC No. 49 and No. 19) and medium tags (NBTC No. 681) were applied on the basis of turtle size. The No. 19 and No. 681 tags have "through-the-hole" locking mechanisms, while the No. 49 tags lock with the "tamper-proof design" (Balazs, 1982).

From 1978 through 1979, all turtles were tagged with a single Monel flipper tag (NBTC No. 49 or No. 681) attached to the trailing edge of the proximal portion of either foreflipper. By 1980, double tagging was begun as a means of assessing tag losses and to increase the chances that at least one tag would remain on the turtle. In the fall of 1980, NBTC No. 49 tags were replaced with NBTC No. 19 tags, which were expected to improve retention rates due to a superior locking mechanism (Balazs, 1982). Triple tagging was begun in the fall of 1981 to further enhance chances of long-term recognition.

Recaptures of turtles bearing NMFS tags were obtained from a variety of sources including shrimp fishermen, gill net fishermen, surf fishermen, power plant intake canals, sea turtle strandings and sea turtle nesting beaches. Multiple captures of the same turtle were treated as independent events with number of days from original capture as days-at-large.

Data were initially separated on the basis of number of tags applied. Turtles receiving a single tag could not be analyzed for tag shedding rates, and triple-tagged turtles were recaptured in numbers insufficient for analysis. Only turtles receiving two tags were recaptured in adequate numbers for determination of tag shedding rates.

Prior to calculating probabilities of tag loss, a Chi-square analysis was used to test for differences in shedding rates between the two types of locking mechanism. Two-by-two contingency tables were constructed for 100-day time increments to compare proportions of turtles bearing one and two tags in the NBTC Nos. 19 and 681 tags versus the No. 49-tags.

Procedures outlined in Seber (1973) were then used to estimate π , the probability that a tag was lost by the middle of each time period. The formula used was:

$$\pi = M_c / (M_c + 2M_{ab})$$

where

M_c = number of turtles recovered in a specific period
bearing one tag, and

M_{ab} = number of turtles recovered in the same period
with both tags remaining

Probabilities of tag loss were regressed on days-at-large using two different weighting schemes. The first scheme used the sample size as weights while the second weighting scheme used the reciprocal of estimated variances as weights. As the results were similar using either method, we chose to present the results using sample size in weighting probability estimates in regression.

Over the study period, 4505 loggerhead turtle (Caretta caretta) captures were recorded. The size composition of these animals was 83% subadult (total straight-line carapace length < 83 cm) and 17% adult (total straight-line carapace length \geq 83 cm). A total of 649 loggerheads bearing NMFS tags have been recaptured since tagging began. The size structure of recaptures was similar in percent composition to total captures, and no differences in shedding rates based on the size of individuals were indicated. Of the recaptures, 146 turtles were originally single tagged, 445 were double tagged and 58 were triple tagged (Table 1).

A summary of double-tagged recoveries, separated by tag locking mechanism, is presented (Table 2). From Chi-square

Table 1. Summary of loggerhead turtle recaptures by days-at-large increments. Recoveries were separated on the basis of number of tags originally applied.

Days at large	Recoveries of single-tagged turtles	Recoveries of double-tagged turtles		Recoveries of triple-tagged turtles		
		Two tags remaining	One tag remaining	Three tags remaining	Two tags remaining	One tag remaining
0-99	76	261	44	37	1	
100-199	15	31	9	9	2	
200-299	10	30	13	1	1	
300-399	11	13	10	1	1	
400-499	14	5	11		1	1
500-599	4	2	5	1	2	
600-699	10	1	4			
700-799	2	2	2			
800-899	3		2			
900-999	1					
Totals	146		445		58	

Table 2. Probabilities of tag loss in loggerhead turtles, Caretta caretta, calculated by 100-day increments. Separate computations for Nos. 19 and 681 tags and No. 49 tags were performed.

DOUBLE-TAGGED TURTLES (No. 49 Tag)			
Days-at-large	Two tags remaining (M_{AB})	One tag remaining (M_C)	Probability of tag loss (π)
0-99	75	12	0.07
100-199	21	5	0.11
200-299	25	8	0.14
300-399	8	1	0.06
400-499	2	2	0.33
500-599	2	2	0.33
600-699	1	1	0.33
700-799	1	2	0.50
800-899	-	1	1.00

DOUBLE-TAGGED TURTLES (Nos. 19 and 681 Tags)			
Days-at-large	Two tags remaining (M_{AB})	One tag remaining (M_C)	Probability of tag loss (π)
0-99	186	32	0.08
100-199	10	4	0.17
200-299	5	5	0.33
300-399	5	9	0.47
400-499	3	9	0.60
500-599	-	3	1.00
600-699	-	3	1.00
700-799	1	-	0.00
800-899	-	1	1.00

analyses, the hypothesis of homogeneity of proportions was not rejected over the lower time increments (0-200 days-at-large) but was rejected in all cases over 300 days-at-large. Pooling of the data in increments of 100-299 and 300-499 was necessary because at least one of the expected frequencies was less than five in non-pooled data. On the basis of these analyses, it is concluded that the data should be separated according to tag locking mechanisms and independent estimates of probability of tag loss computed.

A plot of the probability of tag loss on days-at-large, comparing the shedding rates in the two types of locking mechanism, is presented in Fig. 1. Time increments in which either M_{ab} or M_c equalled zero were omitted, and weighted regressions adjusted through the origin were performed. Results of these analyses indicate that the regression slope of the Nos. 19 and 681 tags was approximately double that of the No. 49 tags.

It is possible that differences in tag loss rates may have been due to incomplete locking of the No. 19 tags caused by improper adjustment of the tag applicators. Incorrect settings of the No. 19 applicators have been shown to result in partial bending and locking of tags (Larry Ogren, NMFS, Panama City Laboratory, personal communication). The majority of the No. 19 tags were applied aboard a shrimp trawler during night towing in the Cape Canaveral, Fla., ship channel. On some nights, as many

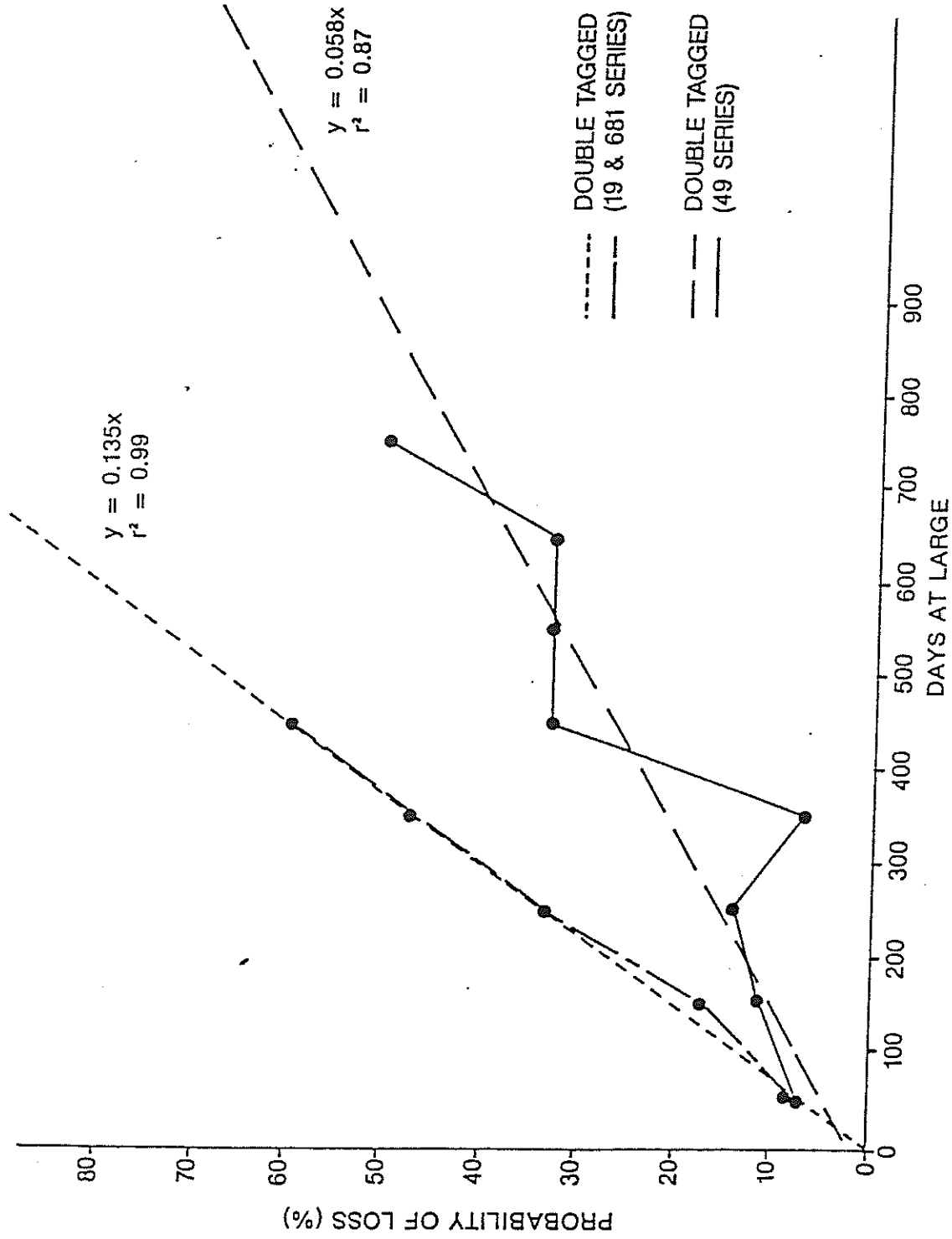


Figure 1. Regression of probability of tag loss on days-at-large for loggerhead turtles, *Caretta caretta*. Two types of flipper tags are compared.

as 40 turtles were tagged, measured and released. The less-than-optimal conditions under which the tagging was accomplished may have contributed to an increased failure to adequately inspect tags to assure that they were locked properly.

Two other known causes of tag loss, tissue necrosis and tag corrosion, undoubtedly contribute to losses but neither readily accounts for the observed differences in shedding rates. The tag locking mechanism should have no effect on tissue necrosis, and tag corrosion over the first year is probably a minor source of losses. Our field observations suggest that corrosion tends to be most prevalent as days-at-large increase.

The results of this study were compared to tag losses in a population of subadult and juvenile green turtles, Chelonia mydas, of the Galapagos Islands (Green, 1979). In an experiment to test retention rates of Monel flipper tags versus plastic rototags, Green (1979) found that 35 of 116 turtles had lost the Monel tag within 500 days. Mrosovsky and Shettleworth (1982), using Green's (1979) data, calculated the probability of losing a metal tag during the time interval of 101-500 days to be 0.38 and from 501-1000 days to be 0.63. These shedding rates are similar to those observed in our No. 19 and No. 681 tags, where probability of loss over these time intervals was 0.37 and 0.78.

It should be noted that the two regression equations, for Nos. 19 and 681 tags and for No. 49 tags, are based on observed tag losses in animals recaptured after days-at-large periods less than 500 and 700 days, respectively. Use of the equations for predicting probability of tag loss over longer time spans is questionable. From published information on nesting female turtles re-nesting after three- and four- year intervals and still retaining Monel flipper tags, (Hughes, 1974; Richardson et al., 1978), it is apparent that tag loss rates must diminish at some point in time. Our regression equations predict a 100% probability of tag loss after 741 days-at-large for the Nos. 19 and 681 tags and 1515 days-at-large for the No. 49 tags.

Additional analyses were performed to determine if initial high probabilities of tag loss attributable to improper tag application could be discerned. Recoveries in the 0-99 days-at-large time period were subdivided into 5-day increments (Table 3). Calculated probabilities of loss for each time increment were weighted by sample size and regressed on days-at-large, omitting time increments in which M_{ab} or M_c equalled zero (Fig. 2). The regression was not adjusted through the origin, because high initial tag losses would be reflected in the y-intercept.

While this analysis did not suggest early tag losses that could be attributed to improper tag application, it does not preclude the possibility that improperly applied

Table 3. Probabilities of tag loss in loggerhead turtles, Caretta caretta, calculated by 5-day increments over the first 100 days-at-large.

DOUBLE-TAGGED TURTLES (Nos. 49, 19 and 681 Tags)			
Days at large	Two tags remaining (M_{AB})	One tag remaining (M_C)	Probability of tag loss (π)
0-4	38	2	0.026
5-9	24	1	0.020
10-14	23	1	0.021
15-19	26	1	0.019
20-24	20	3	0.070
25-29	22	5	0.102
30-34	20	2	0.048
35-39	7	-	0.000
40-44	9	-	0.000
45-49	8	5	0.238
50-54	10	5	0.200
55-59	8	3	0.158
60-64	10	1	0.048
65-69	4	1	0.111
70-74	5	2	0.167
75-79	5	4	0.286
80-84	6	-	0.000
85-89	4	-	0.000
90-94	6	4	0.250
95-99	6	4	0.250
100-104	2	2	0.333

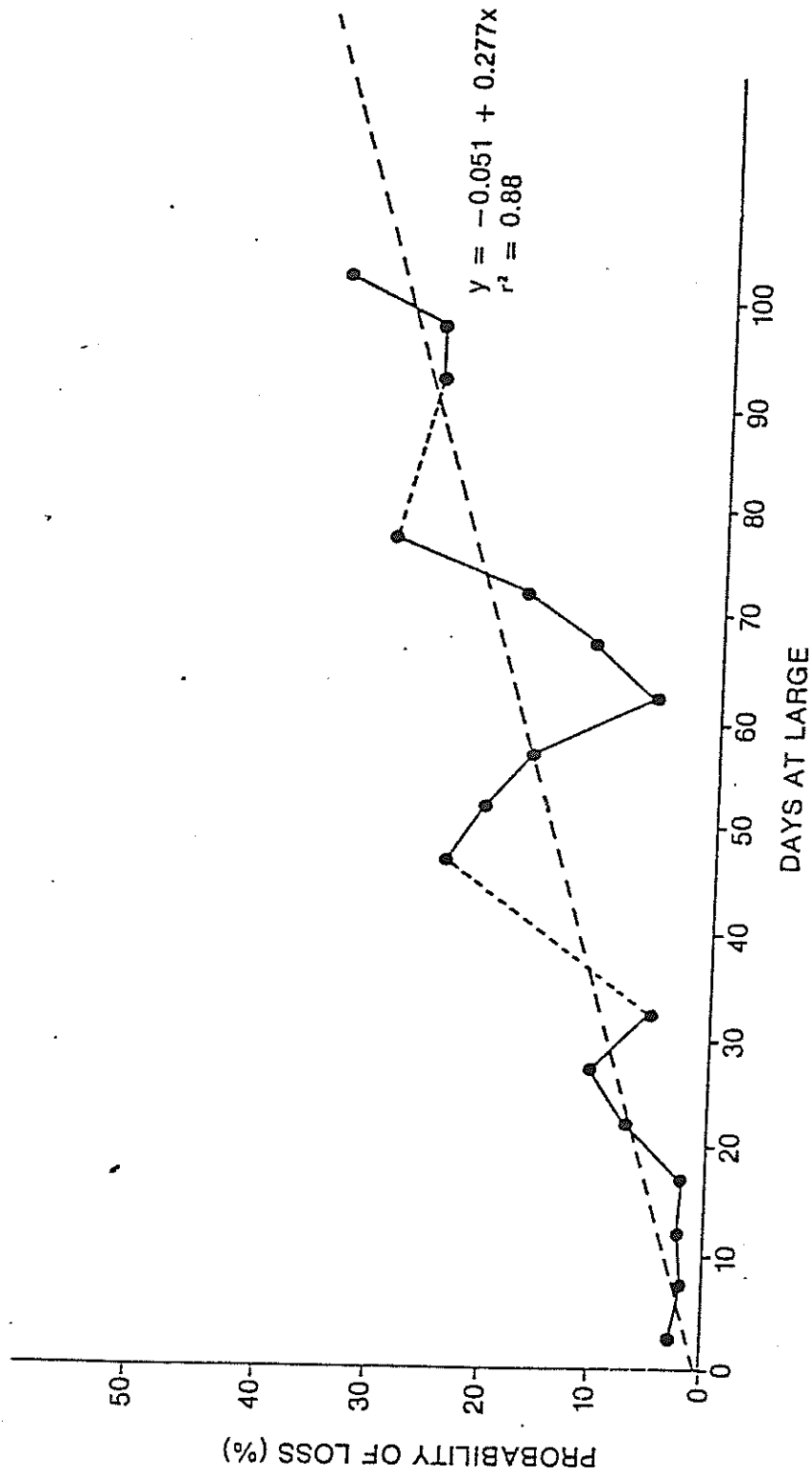


Figure 2. Regression of probability of tag loss on days-at-large for loggerhead turtles, *Caretta caretta*.

tags have a significant effect on tag loss. There is no reason to suspect that all tags improperly secured would be lost over any given time span. We have captured turtles in the field bearing unlocked tags up to two years after initial tagging.

Schulz (1975) conducted an experiment in which 80 nesting female green turtles were tagged and simultaneously marked with paint. Within one month, 12 of these animals were recovered with persistent paint marks, but missing tags. He estimated 15-20% of the turtles tagged would lose their tags within one month. Comparing Schulz's results with our data required a new computation to reflect the percent of turtles expected to lose one tag (Table 4). Estimates of the percent of turtles losing a tag over the first 90 days-at-large ranged from 8-19% and averaged 15%, which is compatible with Schulz's results.

These analyses document that Monel flipper tags are not a reliable permanent tag for loggerhead turtles. Although specific reasons for the poor performance of the tags are unknown, it is probably a combination of factors including improper application, tissue necrosis, and tag corrosion. Recent success with Inconel alloy flipper tags applied to Hawaiian green turtles (Balazs, 1983) indicates that tag loss can be substantially reduced through improved tags or techniques.

Table 4. Percent tag loss in loggerhead turtles, Caretta caretta, over the first 90 days-at-large. Percent loss = $2 pq \times 100$ where: p = probability of tag loss and $q = (1-p)$.

DOUBLE-TAGGED TURTLES (Nos. 49, 19 and 681 Tags)				
Days at large	Two tags remaining (M_{AB})	One tag remaining (M_C)	Probability of tag loss (π)	Percent loss (%)
0-29	153	13	0.0408	8
30-59	62	15	0.1079	19
60-89	34	8	0.1053	19

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IX. KEMP'S RIDLEY (LEPIDOCHELYS KEMPII) AND GREEN (CHELONIA MYDAS) TURTLES CAPTURED BY TRAWL IN THE VICINITY OF CAPE CANAVERAL, FLORIDA (1979-1984)

By

Tyrrell A. Henwood and Larry Ogren

INTRODUCTION

Of the sea turtles which occur in the United States waters, two formerly abundant species (the Kemp's ridley, Lepidochelys kempii, and the green, Chelonia mydas) are presently classified as endangered (Endangered Species Act 1973-16 USC 1531-1543). Green turtle populations were depleted primarily through commercial exploitation of adults (King, 1982), while Kemp's ridley populations suffered from extensive predation on eggs and heavy fishing pressure during the 1950's (Pritchard, 1969).

Although protective measures are now in effect, many aspects of the life histories of these species are unknown, making effective management difficult. One vital gap in our knowledge is the distribution and movements of members of

these species. Without information on age, size class and sex distributions, we are unable to identify habitats which may be critical during stages of the life histories.

This paper presents partial results of National Marine Fisheries Service (NMFS) sea turtle research in Cape Canaveral, FL from 1979-1984. Captures of Kemp's ridley and green turtles were analyzed to determine seasonal occurrence, size composition and movement patterns. For Kemp's ridley turtles, additional capture records from Georgia and South Carolina were included for comparative purposes. We defined the Canaveral area as coastal waters of eastern Florida from $28^{\circ} 15'N$ to $28^{\circ} 30'N$ latitudes (Fig. 1). These limits encompass the Cape Canaveral ship channel, where the majority of our sea turtle captures have occurred.

MATERIALS AND METHODS

Capture records of Kemp's ridley and green turtles from all NMFS sea turtle trawling research projects in the southeastern United States were merged for analysis. Although sampling methodologies and objectives of the projects were different, each recorded location of capture, date, tag identification numbers, species, sex, total carapace length and width, and condition of animals. For purposes of this paper, we were primarily concerned with captures in or near the Cape Canaveral ship channel.

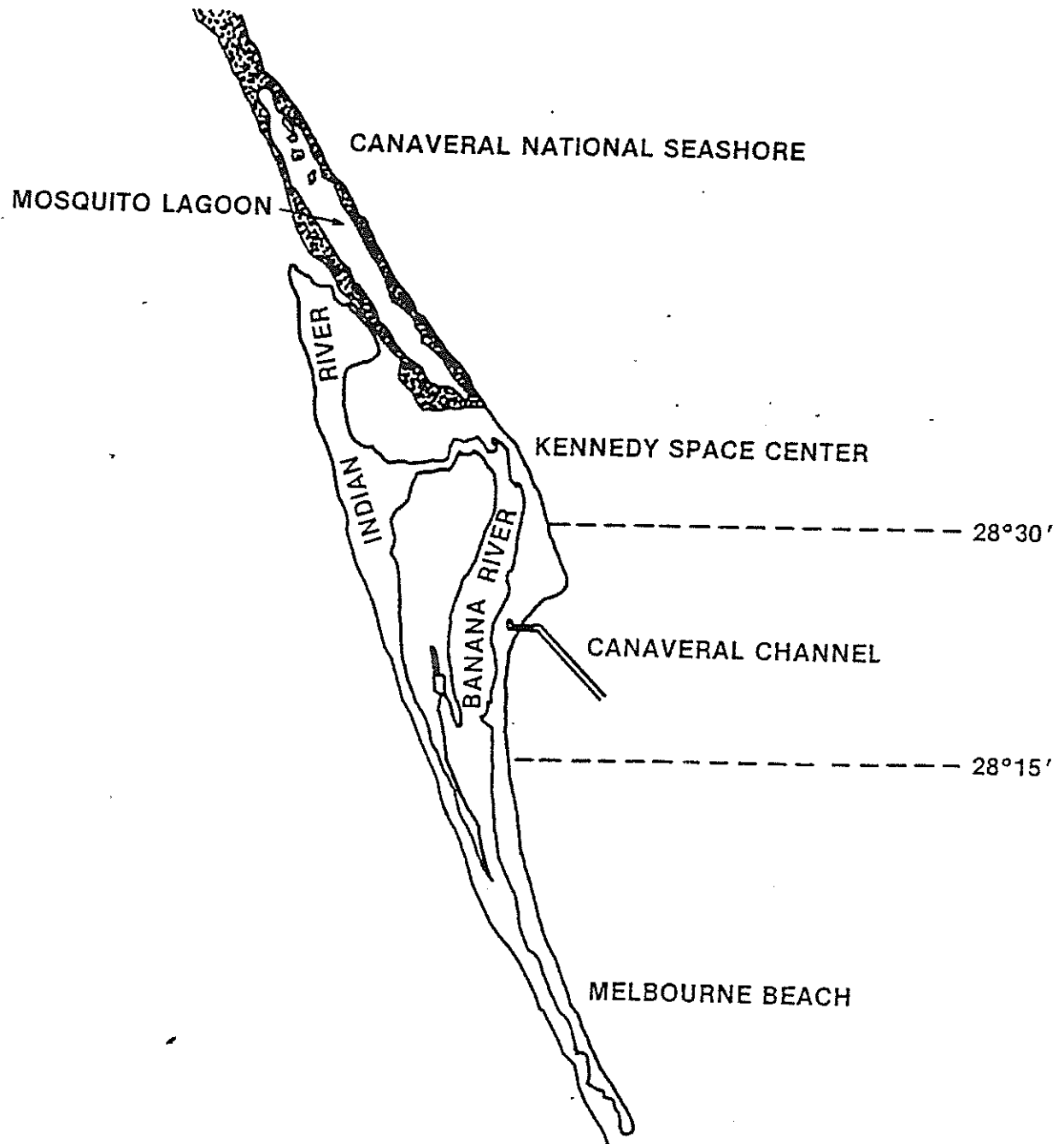


Figure 1. Description of the primary study area including local nesting beaches at Canaveral National Seashore, Kennedy Space Center and Melbourne Beach.

RESULTS AND DISCUSSION

The Green Turtle (*Chelonia mydas*)

Green turtles were captured throughout the study period (Table 1). All green turtles encountered in the Canaveral area were subadults, ranging in size from 23.6 to 68.1 cm total straight-line (SL) carapace length (Fig. 2). Except in August and November, green turtles were captured during all months of the year.

The infrequent capture of green turtles and the lack of seasonality in their occurrence indicates that these animals are random transitory residents of the area. None of these turtles have been recaptured despite continued sampling efforts in the vicinity. The size range of these turtles is similar to the lower range of the green turtle population found in the Mosquito Lagoon (Mendonca and Ehrhart, 1982), and the mean size (34 cm) corresponded to the smallest turtle observed in the Cedar Key-Crystal River feeding pastures on the upper west coast of Florida (Carr and Caldwell, 1956).

The Indian River-Banana River area historically supported a green turtle fishery (Ehrhart, 1983). This fishery flourished during the late 1800's, but ended near the turn of the century. Animals captured in the Canaveral area during this study are in the size range for recruitment to these inshore feeding pastures. Since no grass beds

Table 1. Summary of green turtle, Chelonia mydas, captures in the Canaveral area and adjacent shrimping grounds. Records after April 1983 provided by a single trawler.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Totals
1978											1		1
1979													
1980				1		1	1	1	1	1			5
1981	2				1								3
1982													
1983			2			1					1		4
1984	4	2	1										7
Totals	6	2	3	1	1	1	2	1	1	1		2	20

occur offshore of Cape Canaveral, we assume that green turtles encountered in this habitat are in the omnivorous stages of their development or may be in transit to suitable feeding pastures.

The Kemp's ridley turtle (*Lepidochelys kempi*)

A total of 40 Kemp's ridley turtles have been captured in the vicinity of Cape Canaveral, FL, over the period of these investigations. The sizes of these animals ranged from 24.1 to 66.0 cm (mean = 38.6 cm total straight-line carapace length)(Fig. 3). Except for one instance, these turtles were classified as immature. The 66.0 cm animal was designated a mature female based on the size records given for nesting females (59.5 - 75.0 cm) by Chavez et al. (1967).

The fact that the majority of turtles (39 of 40) were immature, was in agreement with prior Kemp's ridley records from western Atlantic waters (Carr, 1956, 1957, 1980; Carr and Caldwell, 1958). The capture of an adult ridley outside the Gulf of Mexico, however, does mean that adult ridleys occasionally forage along the eastern coast of Florida. In addition to the single adult turtle, five immature animals were over 50 cm carapace length and were probably nearing sexual maturity (Marquez, 1972).

Examination of monthly and yearly captures of Kemp's ridley turtles in the Cape Canaveral area (Table 2),

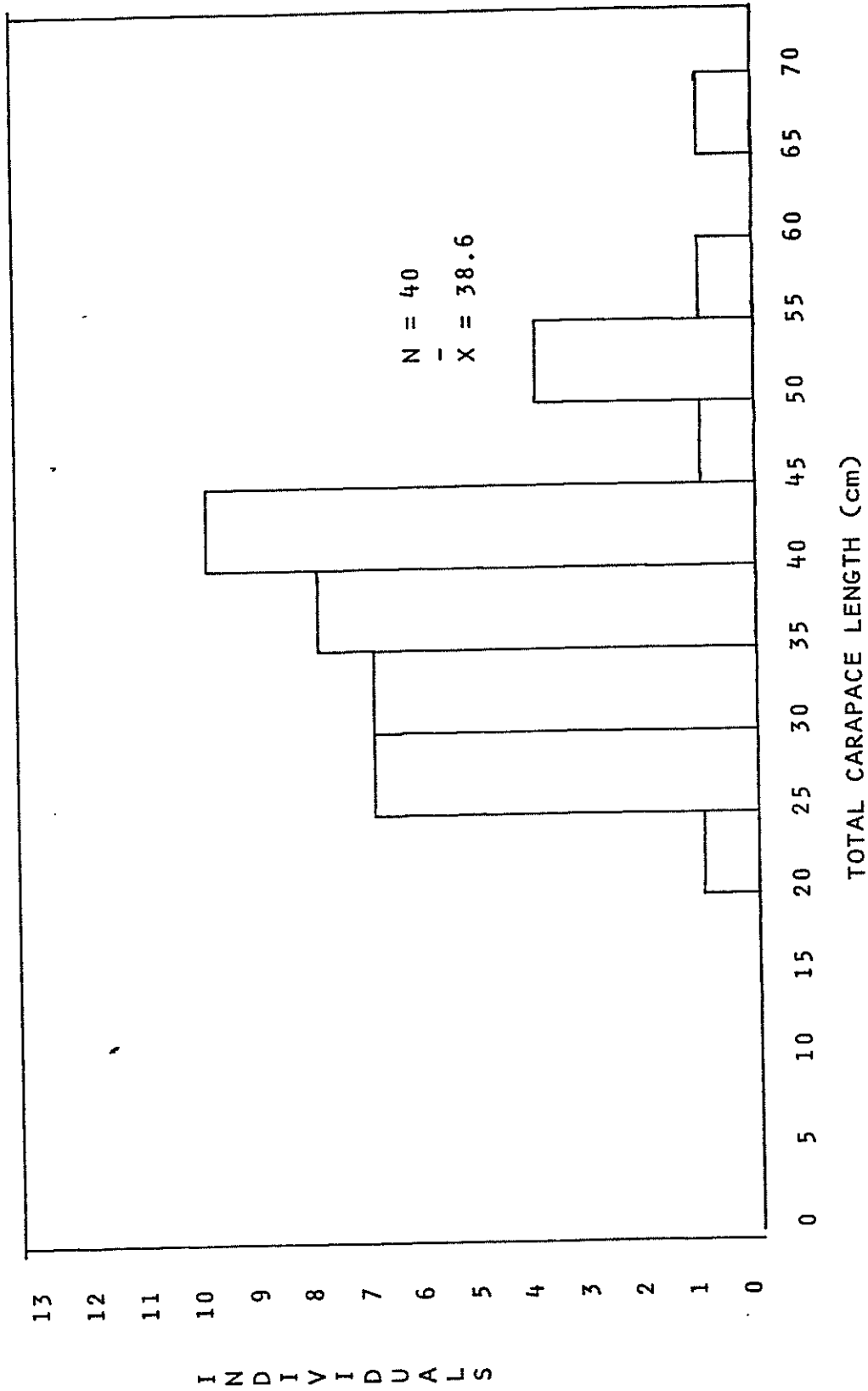


Figure 3. Summary of Kemp's ridley, Lepidochelys kempi, captures in the vicinity of Cape Canaveral, Florida.

Table 2. Summary of Kemp's ridley, Lepidochelys kempi, captures in the Canaveral area and adjacent shrimping grounds. Records after April, 1983 were provided by a single trawler.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Totals
1978		1	2										3
1979							1						1
1980			1									2	3
1981			3										3
1982		2	1										3
1983			2	1		1						2	6
1984	5	13	3										21
Totals	5	19	9	1		1	1					4	40

indicated that 93% (37 of 40) of the captures occurred from December through March. Seasonal trends were similar over all years except 1979. These data document that Kemp's ridleys occur off Cape Canaveral primarily during winter months and less frequently during the remainder of the year.

In addition to the Kemp's ridley captures in the Cape Canaveral area, 21 ridleys have been captured off Georgia and South Carolina (Table 3). All of these turtles were captured incidentally during commercial shrimping activities from June through November. While these data confirm the occurrence of Kemp's ridleys in waters north of Canaveral during summer and fall months, they may not reflect seasonal distribution patterns because little effort was expended during the remaining months of the year. Therefore, no data are available regarding ridley turtle abundance in these areas during the winter months.

The Georgia and South Carolina Kemp's ridley turtles were smaller than the Cape Canaveral turtles (mean = 34.8; range 20.3 to 57.2 cm), though not significantly (Fig. 4). A north-south size gradient in green turtles has been previously noted (Carr, 1952), and our findings suggest that such a gradient may exist in Kemp's ridley turtles as well. This conclusion is in agreement with the findings of Lazell (1980) and Lutcavage and Musick (1985).

A total of five Kemp's ridley turtles have been recaptured over the study period (Fig. 5). Two Kemp's ridley

Table 3. Summary of Kemp's ridley, Lepidochelys kempfi, captures from Georgia and South Carolina.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Totals
1978						1	5	2		1	1		10
1979						3			1	1			5
1980							2			2	1		5
1983										1			1
Totals						4	7	2	1	5	2		21

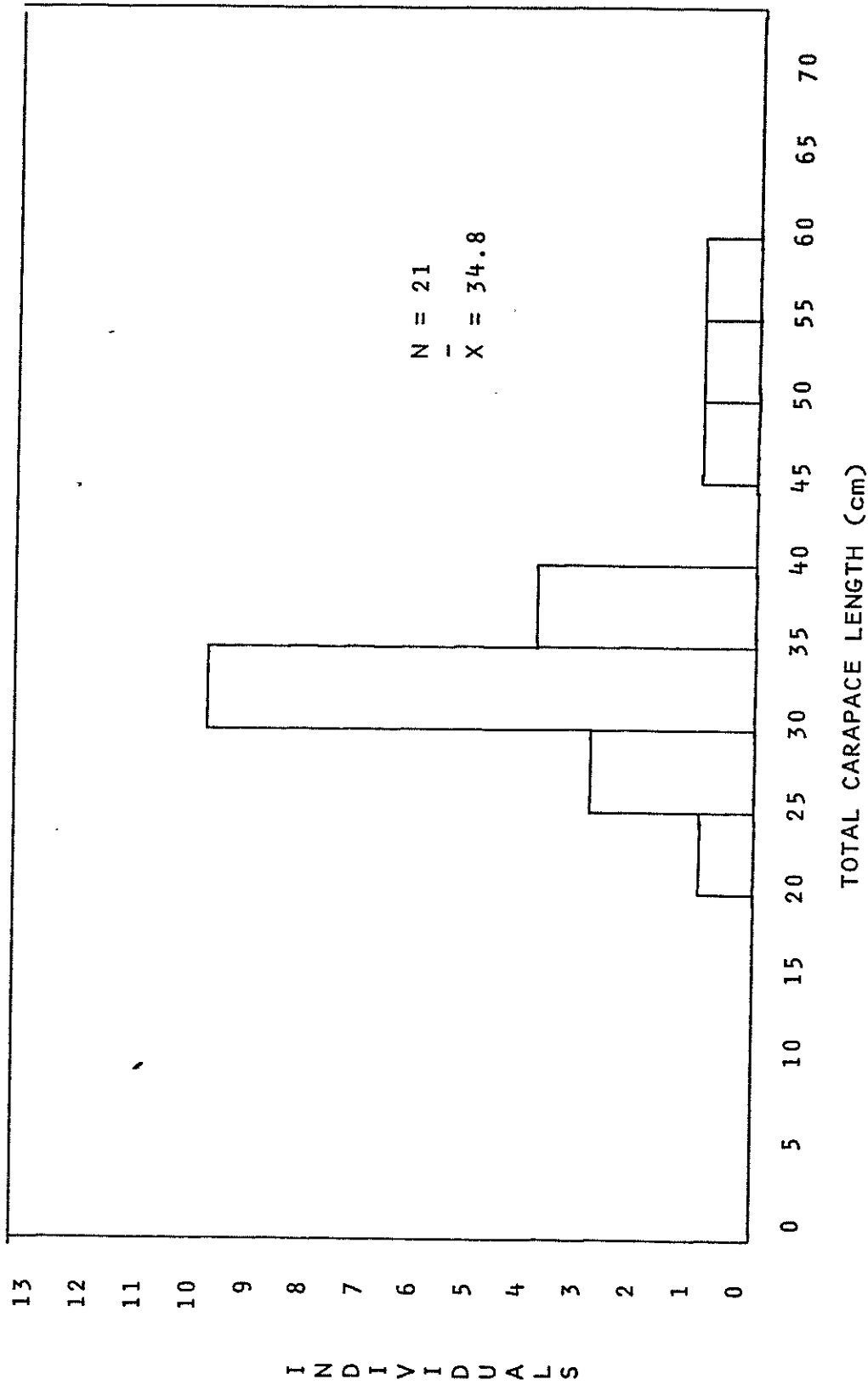


Figure 4. Summary of Kemp's ridley, Lepidochelys kempii, captures off Georgia and South Carolina.

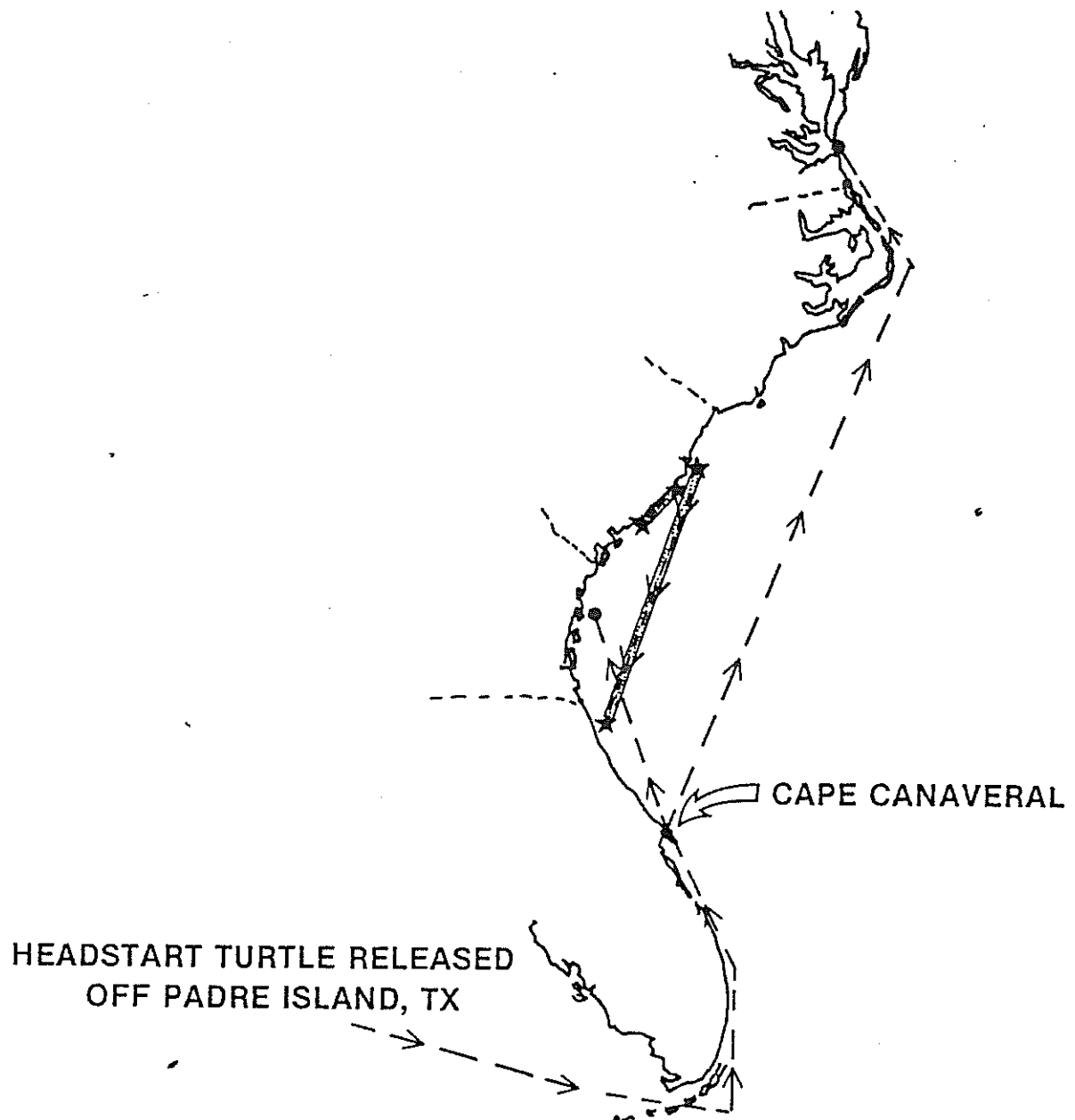


Figure 5. Movements of Kemp's ridley turtles, *Lepidochelys kempii*, based on tag returns. Stars indicate southward movement.

turtles originally tagged in the Cape Canaveral area have been recovered over 170 nautical miles from the Cape. Both were initially captured in February and moved in a northerly direction. The first turtle was captured in 1981 and recovered after 202 days, a distance of 562 nautical miles to the north. The second turtle was captured in 1984 and recovered in May, having moved 173 nautical miles in 102 days.

Another recapture of significance was that of a "headstart" Kemp's ridley released off Padre Island, Texas on June 2, 1982. (Dickie Rivera, NMFS, Galveston Laboratory, personal comm.) This animal was recovered off Cape Canaveral on January 11, 1984 after 589 days-at-large.

The two remaining recaptures are of importance because they provide evidence of southward movement along the Atlantic coast. They also suggest that these movements may be associated with cooling waters in the higher latitudes. One turtle was captured October 5, 1983 off South Carolina and recovered 200 nautical miles to the south after 61 days at large. The second turtle was captured off South Carolina in June, 1979 and recovered in September, 1980, a distance of 37 nautical miles south of the original capture site.

These data, although limited in number, provide some insight into Kemp's ridley movements. As previously noted, highest concentrations of ridleys occurred off Canaveral from December to March. We speculate that ridley turtles

overwintering near Cape Canaveral move northerly along the Atlantic coastline with the warming of waters, foraging at least as far as the Chesapeake Bay. These same turtles reverse directions as waters begin to cool in the fall, returning in a southerly direction. Seasonal movements up and down the coast may continue until the turtles reach sexual maturity, at which time they return to the Gulf of Mexico to breed.

CONCLUSIONS

Of the turtles captured in the vicinity of Cape Canaveral, FL, green and Kemp's ridley turtles comprised just over one percent of the total. The loggerhead turtle, Caretta caretta, was by far the dominant species, comprising the remaining ninety-nine percent of the total captures. The intermittent occurrence of green and ridley turtles, however, indicates that the eastern coast of Florida is in the foraging and feeding range of both. Low numbers of individuals of these two species captured, may reflect their true proportional abundance at Cape Canaveral. The rarity of their capture may also indicate that Cape Canaveral is located near the outer extension of their ranges or that this habitat is not preferred by these species.

The low catches of green turtles in the course of these investigations was not unexpected, since these turtles are

herbivorous during the majority of their lives. They exhibit omnivorous feeding habits during a short phase of their life cycles, and would occur in the Canaveral habitat only at these times or as adults during the nesting season. For this reason, only a small segment of the green turtle population would be present in the sampling area and subject to capture.

In the case of the Kemp's ridley turtle, our catch rates in Florida, South Carolina and Georgia were of interest, because this species was once believed restricted to the Gulf of Mexico. Most researchers now believe (Pritchard and Marquez, 1973; Lazell, 1980; Lutcavage and Musick, 1985) that passive transportation of young Kemp's ridley turtles via the Gulf Stream up the eastern coast of the U.S. may be the usual dispersal pattern. Our findings support this idea, and suggest that immature individuals may remain outside the Gulf of Mexico during much of their lives.

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X. SUMMARY

The results of these investigations provided much needed information on the life histories of loggerhead turtles, and to a lesser extent, on the Kemp's ridley and green turtles. Significant numbers of individuals captured at sea have provided an opportunity to study populations of turtles under conditions not associated with breeding or nesting beaches. The use of trawling gear has made possible the capture of subadult and adult male turtles in addition to adult females. These segments of the population have received little attention in the past due to difficulties associated with their capture.

Several chapters of this dissertation are complete papers which have been or will be submitted to professional journals for publication. Use of this format has resulted in a certain degree of redundancy since each paper must stand alone, but hopefully this will not detract from the overall content.

In chapter IV, I described morphometric relationships in western Atlantic loggerhead turtles. Regressions of carapace length, carapace width, weight and total tail length using both over-the-curve and straight-line

measurement techniques were performed in all combinations. Conversion formulae for comparisons between different measurement techniques were developed and condition factors (C) were computed.

These analyses have provided the most comprehensive description of morphometric relationships in loggerhead turtles of the southeastern United States published to date, through inclusion of subadult and adult males with adult females. Relationships of carapace length and width were significantly different in subadult and adult turtles, indicating that the general carapace shape changes as turtles mature. These findings imply that turtle growth patterns change with age, and that growth in adults is restricted primarily to the longitudinal axis.

Condition factors in loggerhead turtles were computed for subadult and adult animals by month, providing information on the mean and range of turtle conditions encountered. Other researchers may find the condition factor useful as an index of the general health of individuals or groups of individuals, particularly if careful consideration is given to comparisons between individuals of similar age, sex, season and stage of development.

In chapter V, I estimated age, growth, survival and mortality rates in loggerhead turtles based on recoveries of previously tagged and measured individuals. Observed growth

in carapace length was fitted to the von Bertalanffy and logistic models and subsequently, age at size estimates were derived. Using these estimates, survival and mortality rates were computed by assigning an age to all individuals ($N = 4,505$) and plotting the natural logarithm of number of individuals on age.

These estimates, while preliminary in nature, are essential to adequately describe changes in populations. Prior to these investigations, estimates of age at sexual maturity in loggerhead turtles have ranged from six years to over fifty years. I estimate that turtles may begin breeding at 22 years of age with mean nesting age of 44 years.

The survival and mortality rates presented in this paper are dependent on accurate age estimates, and are valid only if age estimates are correct. My estimates of mean survival and mortality rates (0.93 and 0.07, respectively) are based on high longevity estimates from the von Bertalanffy growth model. If loggerhead turtles are long-lived species, high survival rates and low mortality rates would be expected.

In chapter VI, I described movement patterns of loggerhead turtles based on recaptures of animals originally captured in the vicinity of Cape Canaveral, FL. Three distinct groups of turtles (adult males, adult females and subadults) occurred in the area and each was dominant at

different times of the year. For this reason, movements of each group were analyzed separately.

The east coast of Florida supports the second largest nesting population of loggerhead turtles in the world. In the spring of each year, adult females migrate into the Cape Canaveral area for nesting. The data indicate that adult males preceded the females, and were dominant during the month of April. Females and males occurred in equal numbers during the month of May, and the males left the area by June. Female nesting continued through August, at which time they migrated to distant foraging and feeding pastures. During the remainder of the year, a population composed primarily of subadult turtles was resident.

Approximately eighty percent of the turtles captured in the Cape Canaveral area were subadults, and the majority of the recaptures were from this group. With the exception of two individuals taken in the Bahama Islands, all long distance subadult recaptures were to the north in coastal waters of Georgia, South Carolina, North Carolina and Virginia. This suggests that subadult turtles from Cape Canaveral may move north during spring and summer months as waters warm in the higher latitudes.

The data also indicated that adult males do not migrate with the females, and may remain in the vicinity of nesting beaches throughout the year. If this is the case, the same males would be available to breed with different groups of

females each year. The total population of males could therefore, be approximately one third that of females, since females are on two, three and four year nesting cycles.

In chapter VII, the seasonality and abundance of loggerhead turtles in the Cape Canaveral ship channel and in four additional eastern Florida channels and inlets was estimated. These analyses are of particular importance because, for the first time, a standard method has been developed that provides sea turtle abundance estimates with approximate standard errors.

Estimates of turtle abundance in the Cape Canaveral ship channel ranged from 701 ± 291 turtles in late February, 1982 to a low of 38 ± 26 turtles in late August, 1982. Turtle abundance in the remaining four channels was low during all quarterly surveys, indicating that only Cape Canaveral harbors concentrations of turtles throughout the year and particularly during winter months.

In chapter VIII, I addressed the problem of tag shedding in sea turtles. The probability of tag loss over time must be known to develop meaningful population estimates from tag-recapture data because failure to consider tag losses can lead to serious overestimation of population abundance. Based on observed tag losses in double-tagged turtles, regression equations for tag loss over time were developed for Monel flipper tags. On the

basis of these analyses, I concluded that these tags are not a reliable permanent tag for loggerhead turtles.

Chapter IX summarizes all captures of Kemp's ridley and green turtles in the vicinity of Cape Canaveral, Florida. Both of these species occurred infrequently, comprising less than one percent of the total captures. Their occurrence in the samples, however, indicated that both species forage or migrate through the area and that they utilize this habitat during certain stages of their life cycles.

Recommendations

As is often the case in scientific investigations, particularly when the species being studied is poorly understood, better information could have been obtained with improved methodologies and techniques. The major shortcomings of the data have been mentioned in the papers. It is hoped that other researchers can benefit from problems encountered in this research and that future studies can refine some of my preliminary estimates.

Probably the major drawback to the analyses was the error in measurements. This error was insignificant when comparing between animals, but was of major importance when attempting to measure growth. An error of ± 1.0 cm is not large when dealing with a 100 cm animal, but is very large when dealing with a mean growth rate of 1.62 cm/yr. Researchers attempting to determine growth rates in wild turtles must develop a more accurate measurement technique,

and will probably have to perform these measurements under laboratory conditions and not on the deck of a moving vessel.

Another area which obviously needs improvement is the method of tagging turtles. Tags used throughout these investigations were inadequate and of the 4,505 loggerheads tagged, very few probably still retain flipper tags. This represents a tremendous drawback, since we could potentially have continued to receive information on these animals every time they were captured over their lifespans.

Additional research in the Cape Canaveral area could provide answers to many of the questions raised by these investigations. In particular, the question of whether adult males breed annually is extremely important in developing total population estimates and in management of the species. This problem could be addressed by sampling during the months of April and May over a two or three year period using an improved tag with high probability of retention.

Another question which should be addressed is why turtles cóngregate in the Canaveral ship channel and whether these animals are hibernating during winter cold spells. If we could determine what factors attract turtles to this area, it should be possible to identify other locations with similar conditions, which now support, or could potentially support, turtle populations. This knowledge would be useful

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